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Proposed Design Modifications of the Refueling and Spent Fuel Storage Systems of the Advanced Neutron Source Reactor

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Student Design Competition

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Abstract

The Advanced Neutron Source (ANS) Reactor, a project currently under development at Oak Ridge National Laboratory in Oak Ridge, Tennessee, will be a "first of a kind" high neutron flux facility capable of providing a superior source of neutrons for scientific research. The ANS design team requested that the University of Tennessee Nuclear Engineering Department Design Class analyze gamma heating in a number of different locations within the spent fuel removal and storage system. The analyses and proposed solutions to these issues will be incorporated into the conceptual phase of the plant design.

Based upon calculations performed with a one-dimensional radiation transport and thermal analysis model for the spent fuel pool, it is recommended that the ASTM-04 concrete currently selected as the structural material be replaced with Magnetite, MA-a concrete. It is further recommended that a 5.08 cm (2 in) steel liner be installed along the pool wall on the concrete surface. With these modifications, a minimum distance of 80 cm (2.63 ft) between the fuel and the pool wall will ensure that the structural integrity of the concrete is maintained.

Based on calculations performed using the Monte Carlo code MORSE-SGC, it was found that a fuel element could be raised an additional 3.04 m (10 ft) while still maintaining a dose rate limit of 25 mrem/hr to a person at the Fuel Handling Cell storage pool edge. Elevating the concrete dam and transfer lock 152.4 cm (5 ft) will preserve a spacing of 152.4 cm between the fuel and concrete throughout the fuel transfer to the spent fuel pool. This spacing maintains a minimum safe level of water in the event of a planned or unplanned pool drainage and ensures the integrity of the concrete in these areas.

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1.0 Introduction

1.1 Background

The Advanced Neutron Source (ANS) reactor is a project currently under development at Oak Ridge National Laboratory in Oak Ridge, Tennessee. The primary goal of this project is to build a "first of a kind" facility capable of providing a superior source of neutrons for experimentation in the nuclear industry. Applications of this facility will encompass a wide range of technologies including medicine, biology, metallurgy, chemistry, food technology, polymer science, physics, and neutronics. The preliminary design of this experimental reactor began almost ten years ago when researchers at Oak Ridge recognized the growing demand for a well-developed source of fast and thermal neutrons for use in specialized neutronics research.

Since that time, a number of intermediate design proposals have been developed by the ANS project committee. The latest design consists of a 330 Mw(f) research reactor that is heavy water cooled and moderated.[1] The entire system is submerged beneath a light water pool. The reactor operates on a twenty-one day fuel cycle - a 17 day power operation with a 4 day refueling period. A schematic of the reactor building is presented in Figure 1.1. Because of its unique configuration, the reactor design imposes several refueling requirements to ensure that the two water inventories remain separate.

The ANS fuel assembly is a split core composed of an upper and lower fuel element. The upper element contains approximately two-thirds of the fuel loading (see Figure 1.2 for a diagram of the upper element). During refueling, the assembly is handled as two separate elements. Each element is allowed to cool in the core position for 24 hours before the refueling process begins. Absorbers are attached to the elements to ensure subcriticality during transport and storage. The refueling procedure occurs through the top of the reflector vessel. Each element is transported out of the core

through a "stack" of heavy water. When it reaches the top of the stack, the element is transferred over a concrete dam into a heavy water storage pool where it is allowed to cool for 42 days (2 fuel cycles). Consequently, this storage pool is designed to accommodate two complete fuel assemblies. After temporary storage, the elements are transported through a D_2O / H_2O fuel transfer lock to a light water storage pool. The elements remain in this light water pool for two years. Finally, they are moved to a 5 year light water storage pool in the reactor support building until the time of permanent disposal.

One concern that has developed over the past year involves the integrity of the materials utilized in the refueling and storage processes. Gamma radiation released by the spent fuel elements causes internal heat generation in the surrounding concrete structures. Since extreme temperatures, radiation doses, and heat generation rates lead to deterioration of concrete, a careful analysis of the gamma heating in the ANS fuel storage facilities has become a primary objective in the continuing design process. In January 1993, the ANS project design team suggested that students at the University of Tennessee analyze this problem of gamma ray heating in concrete. After careful consideration and deliberation, this project was selected from a number of suggested problems for entry into the 1993 Student Design Competition sponsored by the American Nuclear Society.

Figure 1.1 Schematic of ANS Reactor Building, Fuel Handling Area, and Secondary Basin Pools

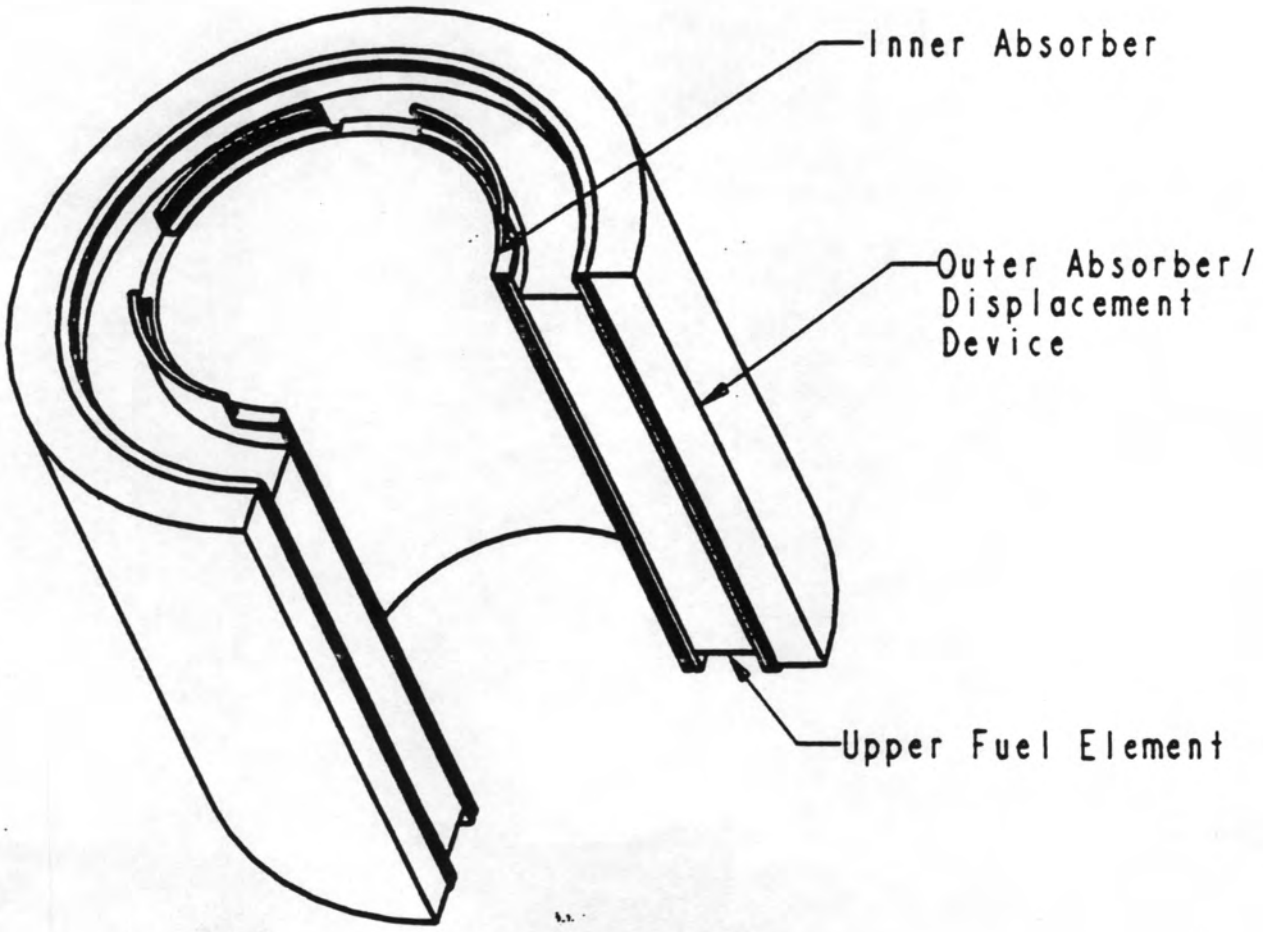
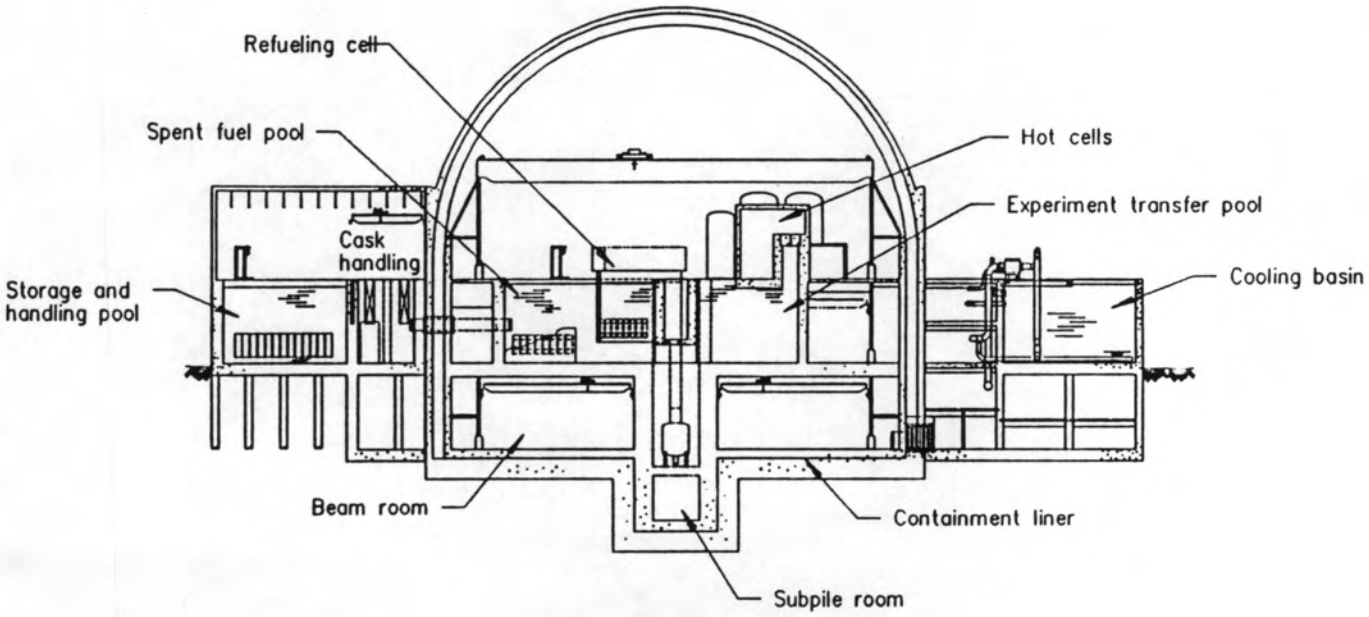


Figure 1.2 Upper Fuel Element With Absorbers



1.2 Problem Description

As of January 28, 1993, design requirements had been imposed on the ANS design team that required a distance of 152.4 cm to be maintained between the spent fuel and the concrete to avoid damage to the concrete due to the gamma heating from the fuel. There will be occasions when this clearance would be difficult to maintain. The ANS design team requested that the UT design class analyze potential design modifications that would meet the intent of the required spacing without requiring the 152.4 cm distance.[2] There are four locations where design alternatives need to be considered. These four locations are described below.

1. The Light Water Spent Fuel Pool

   An array of 35 to 50 spent fuel elements of various decay heat levels are expected to be stored in this pool As of January 28, 1993, a distance of 152.4 cm was required between the fuel and the pool wall. The ANS Design Project Team proposed the addition of a pool liner or the installation of a special cooling system for the concrete surface as possible design modifications.

2. D_2O/H_2O Transfer Lock

   A transfer lock has been designed to transfer fuel elements from heavy water to light water. The requirement of a 152.4 cm distance between the spent fuel and the concrete has necessitated the design of a lock that is much larger than desired. Again, a liner or cooling system has been proposed as a possible design modification to allow for the design of a smaller lock.

3. Heavy Water Storage Location

   The plans as of January 28, 1993 called for the two hottest fuel elements to be stored in a heavy water reservoir. This reservoir has been designed to a size much larger than required for the fuel storage due to the 152.4 cm space requirement.

4. Fuel Transfer Tunnel

   Movements of the spent fuel elements within the refueling stack will position the elements closer to the concrete than the 152.4 cm requirement.

Each of these four locations have been analyzed by the undergraduate design group. The proposed design modifications are included in the body of this report.

1.3 Scope and Organization

Section 2 of this report summarizes the calculation of the spent fuel gamma decay source using a point depletion code. The results of the calculation are discussed and compared to previously calculated results.

Section 3 presents the efforts to benchmark the calculational methods used in the project against independently established calculations. The extension of these verified calculational techniques to the current design of the ANS spent fuel pool and the heavy water storage area are also discussed.

Section 4 discusses the proposed solutions to the ANS design issues in the spent fuel pool and the heavy water storage area. This section describes the procedures and models used to obtain solutions to the problems and the rationale behind the selection of proposed solutions.

Section 5 provides a summary of the proposed solutions and presents future work proposals.

The final sections of the report are appendices which provide detailed information about various aspects of the project. Appendix A provides an explanation for the theory and a listing of the FORTRAN program TEMPROFV, developed in this study and used in the calculation of temperature profiles. Appendix B details the procedure used to collapse the nineteen group DKPOWR source to the eighteen group structure for use in SCALE. Sample input files for SAS3, SAS1, CSAS1X, COUPLE, and ORIGEN-S are given in

Appendix C. Appendix D provides information on concrete compositions, properties, and NRC requirements. Appendix E contains the original problem description as submitted by Doug Selby. Finally, initial handbook type calculation results are given in Appendix F.

2.0 Spent Fuel Gamma Source Calculation

The accurate determination of the gamma source strength from the ANS spent fuel elements is crucial for performing reliable shielding calculations. The gamma source was calculated using the ORIGEN-S code in the SCALE code system.[3] Previously calculated results (using the DKPOWR code) were subsequently obtained from Idaho National Engineering Laboratory (INEL).[4] The source strengths obtained using ORIGEN-S agreed with the DKPOWR findings at initial decay periods to within 3%, but were as much as a factor of two lower at later decay times. The decision was made to utilize the DKPOWR results in the analysis since doing so would be conservative.

2.1 Source Calculation Method

Two approaches are available in the SCALE system for fuel depletion calculations. The first method utilizes the SAS2 module which performs pressurized water reactor (PWR) fuel assembly depletion calculations using the ORIGEN-S point depletion code. This method was deemed unsatisfactory due to the inherent inaccuracy of approximating the annular ANS fuel element geometry as a PWR lattice assembly.

The second and preferred method was running ORIGEN-S as a stand-alone module within the SCALE system to perform a point depletion calculation. ORIGEN-S requires as input a basic binary library containing cross sections, decay constants, branching fractions, etc. This input library can be updated with an AMPX cross section library using the COUPLE module in SCALE.[5] The COUPLE module collapses the AMPX cross section library to the three group structure required for input to ORIGEN-S and updates the ORIGEN-S binary input library. The CSAS1X module performs a one-dimensional discrete ordinates transport calculation using the XSDRNPM-S functional module, which produces a cell-weighted cross section library suitable for input to the

COUPLE module. CSAS1X calls the BONAMI-S and NITAWL-S modules to produce working nuclide cross section libraries.

Two CSAS1X models describing the upper and lower fuel elements of the ANS reactor core were obtained from Oak Ridge National Laboratory (ORNL). Two CSAS1X calculations were performed to produce cross section libraries for the upper and lower fuel elements. The COUPLE module was then used to collapse the cell-weighted cross section libraries to three groups for input to ORIGEN-S and to update the ORIGEN-S binary library. ORIGEN-S depletion calculations were then performed.

2.1.1 Approximations in Calculation Method

The first approximation in the calculation method involves the CSAS1X models of the ANS fuel elements. These models of the ANS core do not include the control rod cluster at the center of the fuel annulus. A suitable representation for the control rods was not available; the control rods are continuously withdrawn from the core during the fuel cycle and a time-dependent transport calculation was not available for the fuel cycle. In addition, a single transport calculation was used to approximate the entire fuel cycle. These approximations definitely introduce some error into the subsequent ORIGEN-S calculation, but the magnitude of this error is not known.

The ORIGEN-S calculation requires a description of the core power level over the course of the fuel cycle. Since two separate calculations were required for the upper and lower core, a power history for each fuel element is needed. These numbers were unavailable and their calculation would require a calculation beyond the scope of this project. Each fuel element was assumed to produce 50% of the total core power of 330 MW(f) and to remain constant over the course of the fuel cycle. This assumption can be justified by the fact that at different points in the fuel cycle, each element can be producing more or less than 50% of the core power. Thus 165 MW(f) is an average value.

A final approximation was to perform a full core calculation at 330 MW(f) with the total uranium fuel loading but using the cross section library produced for the upper fuel element only. It was not possible to model the split-core of the ANS reactor accurately with a single one-dimensional transport calculation, and a two-dimensional transport code was unavailable. The upper fuel element cross section library was chosen for the full core ORIGEN-S calculation because the larger fraction of the uranium fuel loading is in the upper fuel element. The results of the full core calculation and the single fuel element calculations are shown in Table 2.1. The full core calculation results agreed favorably with the sum of the single fuel element calculations (see Table 2.1).

Table 2.1 Comparison of Full Core ORIGEN-S Calculation Versus Sum of Single Element Calculations

Decay Time	Lower Element Gamma Decay Power	Upper Element Gamma Decay Power	Upper + Lower Elements Gamma Decay Power	Full Core Gamma Decay Power	Percent Difference
(days)	(MeV/s)	(MeV/s)	(MeV/s)	(MeV/s)	(%)
0	2.79E+19	2.96E+19	5.75E+19	5.95E+19	3.4
1	1.66E+18	1.64E+18	3.29E+18	3.28E+18	-0.5
2	1.23E+18	1.21E+18	2.45E+18	2.43E+18	-0.6
3	1.03E+18	1.01E+18	2.04E+18	2.03E+18	-0.5
4	8.98E+17	8.87E+17	1.78E+18	1.78E+18	-0.5
21	2.80E+17	2.81E+17	5.61E+17	5.59E+17	-0.3
42	1.31E+17	1.34E+17	2.65E+17	2.65E+17	-0.1
63	8.12E+16	8.44E+16	1.66E+17	1.66E+17	-0.1
84	5.98E+16	6.27E+16	1.22E+17	1.22E+17	-0.1
105	4.78E+16	5.05E+16	9.83E+16	9.82E+16	-0.1
126	3.95E+16	4.21E+16	8.15E+16	8.15E+16	-0.1
147	3.30E+16	3.55E+16	6.85E+16	6.85E+16	-0.1
168	2.78E+16	3.01E+16	5.79E+16	5.79E+16	-0.1
189	2.35E+16	2.56E+16	4.91E+16	4.91E+16	0.0
240	1.58E+16	1.76E+16	3.34E+16	3.34E+16	0.0
300	1.03E+16	1.18E+16	2.21E+16	2.21E+16	0.0
365	6.84E+15	8.14E+15	1.50E+16	1.50E+16	0.0
548	2.98E+15	3.74E+15	6.72E+15	6.72E+15	0.0
730	1.71E+15	2.16E+15	3.88E+15	3.88E+15	0.1
913	1.10E+15	1.36E+15	2.46E+15	2.46E+15	-0.1
1095	7.43E+14	8.97E+14	1.64E+15	1.64E+15	0.1
1278	5.31E+14	6.19E+14	1.15E+15	1.15E+15	0.1
1460	4.02E+14	4.52E+14	8.54E+14	8.54E+14	0.1
1643	3.22E+14	3.49E+14	6.71E+14	6.72E+14	0.1
1825	2.72E+14	2.86E+14	5.58E+14	5.59E+14	0.1

2.2 Results of ORIGEN-S Source Calculation

The results of the ORIGEN-S calculation agree approximately with expected values of previous ORIGEN calculations for the High Flux Isotope Reactor (HFIR).[6] The expected value of the total source strength at one day decay time for the ANS fuel should be approximately 3.9 times that of the HFIR source term. The 3.9 factor is the ratio of the ANS power to HFIR power. At larger decay times, the ANS source strength should approach 2.2 (the MWD ratio of ANS to HFIR) times the HFIR source strength.[7] As shown in Figure 2.1, the calculated source strength ratio is 4.43, slightly higher than the 3.9 factor expected. At longer decay times (4.85 years), the source strength ratio is 2.3, also slightly higher than the 2.2 value expected. Figure 2.2 shows a comparison between the calculated ANS source terms and the HFIR and scaled HFIR values. This figure shows that the ANS source term approaches the expected scaled (2.2) HFIR source term at longer decay times.

2.3 Comparison of Calculated ANS Results to DKPOWR Results

A comparison between the ANS results calculated in this study and the DKPOWR results show some differences. Expected decay factors are shown in Table 2.2 along with the ORIGEN-S and DKPOWR results.[7] The ANS source strengths calculated with ORIGEN-S match the estimated decay rate more closely than the DKPOWR results. Table 2.2 shows that the DKPOWR source decayed less at each time interval and has a higher source strength. The higher values for the DKPOWR source are supported by Figures 2.3 and 2.4. The ORIGEN-S results and the DKPOWR results agreed at zero decay time and at approximately 800 days decay. Figure 2.5 shows that although the total gamma strengths agreed at low decay times, the source spectra differ. Some of these differences can be attributed to different energy group structures between the calculations.

The source spectra do follow the same trends, however, which lends credibility to the calculations.

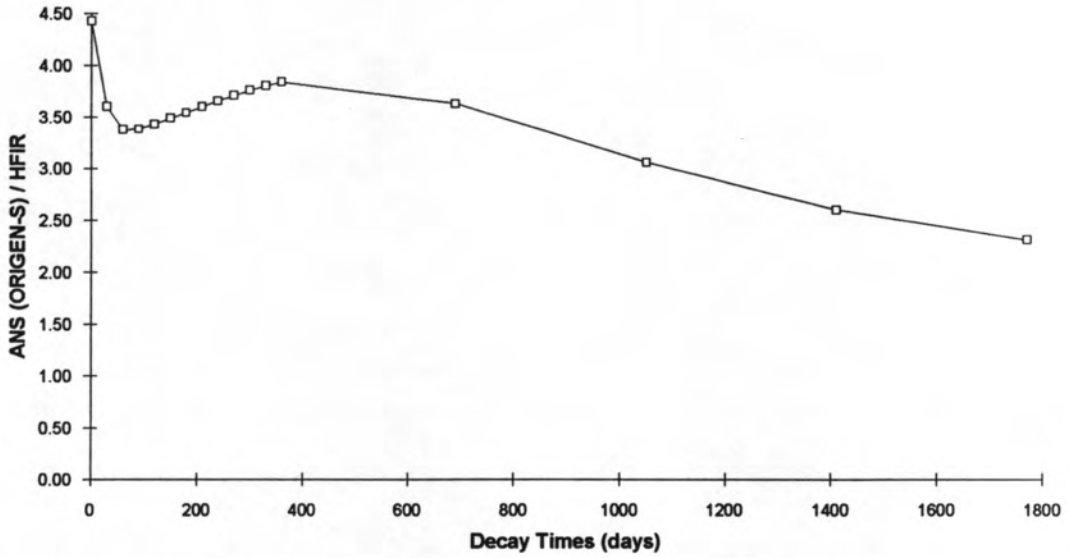


Figure 2.1 ANS to HFIR Source Strength Ratios

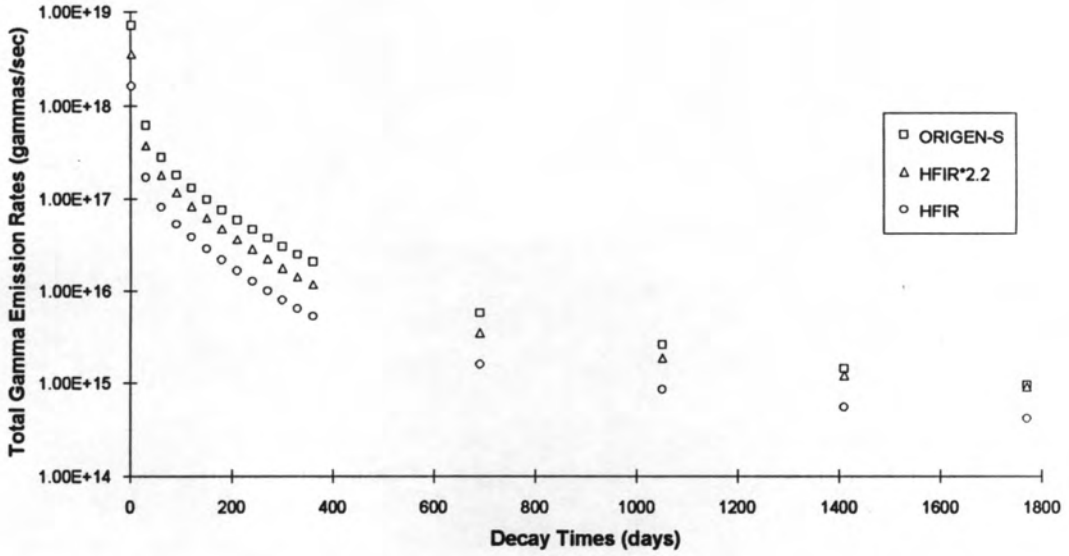


Figure 2.2 Comparison of ANS, HFIR, and Scaled HFIR Source Strengths

Table 2.2 Expected Source Strength Decay Factors for ANS Spent Fuel

Decay Interval	Expected Decay Factor	ORIGEN-S	DKPOWR
1 to 21 days	6	5.9	3.6
21 to 42 days	2	2.1	1.8
1 day to 1 year	233	219	178

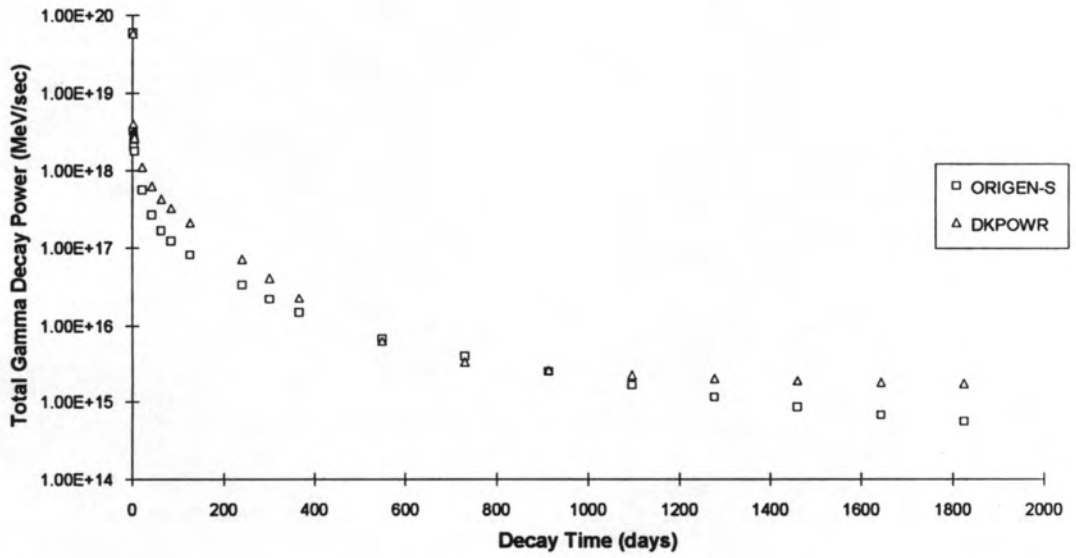


Figure 2.3 Comparison of ORIGEN-S and DKPOWR Gamma Decay Power Values

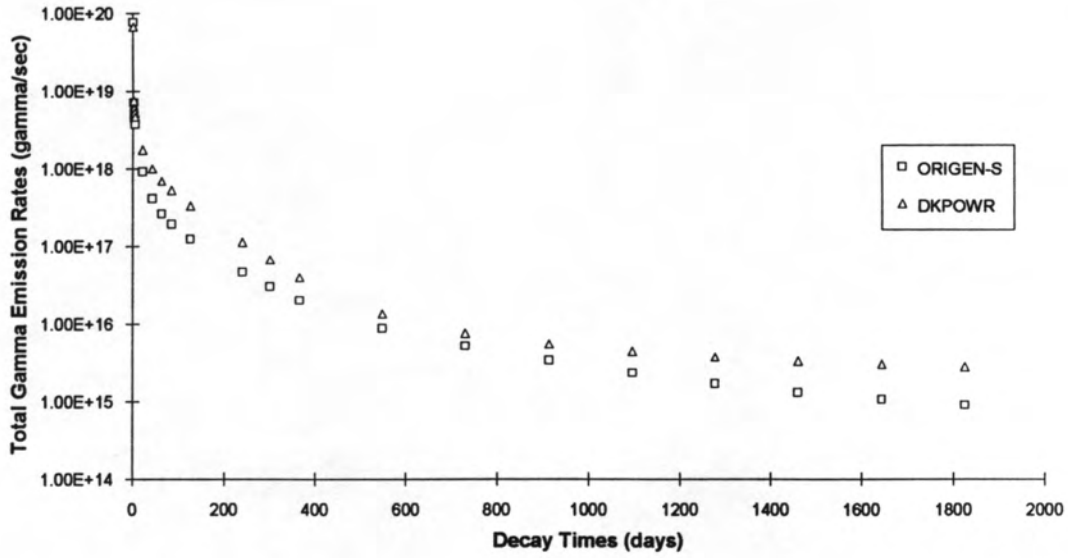


Figure 2.4 Comparison of ORIGEN-S and DKPOWR Gamma Emission Rate Values

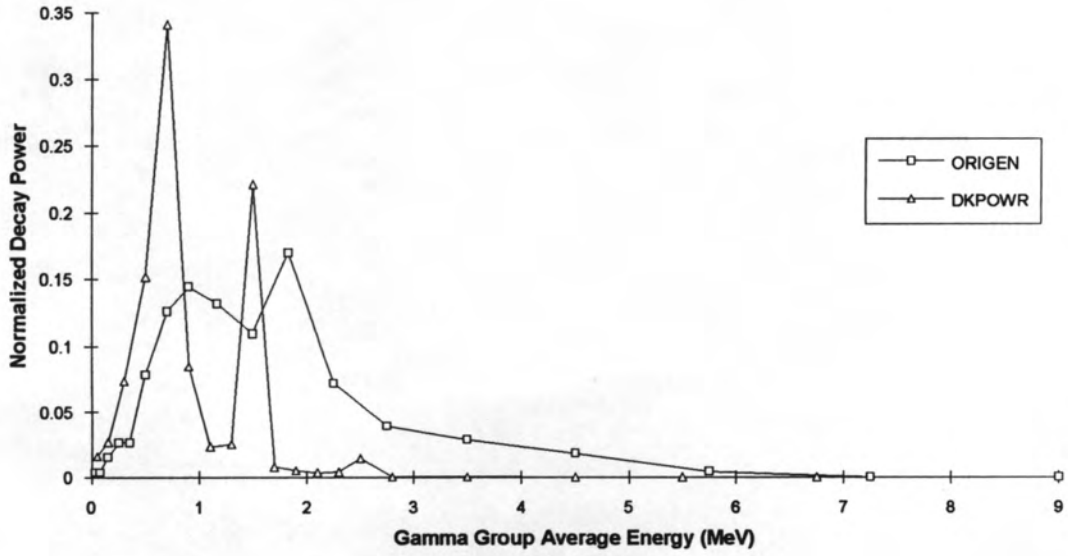


Figure 2.5 Comparison of ORIGEN-S and DKPOWR Gamma Spectra at One Day Decay

2.4 Summary of Gamma Source Calculation

The calculated ORIGEN-S values tend to agree better with the expected values than do the DKPOWR source strengths. Another advantage of the ORIGEN-S calculation is that the correct energy group structure for the source term is available, whereas the DKPOWR results must be collapsed to the correct group structure. However, the DKPOWR source strength is generally higher than the ORIGEN-S source and is thus more conservative. The accepted course of action was to utilize the more conservative DKPOWR source in the shielding calculations.

3.0 Problem Verification / Models Benchmarking

3.1 Reproduction of HFIR Spent Fuel Pool Analysis

Before modeling of the ANS Spent Fuel Pool could be initiated, it was necessary to ensure that the models to be used produced reliable results. The two models, a three-dimensional model and a one-dimensional model, were tested by conducting an analysis of the HFIR Spent Fuel Pool similar to that described in reference 6.

3.1.1 Three-Dimensional Transport Calculations

The University of Tennessee (UT) undergraduate design group recognized immediately that one of the most useful tools applied in the analysis of this problem would be the neutral particle transport codes. The proximity of UT to the Oak Ridge National Laboratory (ORNL) led to the choice of the SCALE system.[3] The SCALE system of codes was originally developed at ORNL at the request of the United States Nuclear Regulatory Commission. The system is a collection of computer codes and cross section libraries necessary for criticality, shielding, and thermal analysis of the spent fuel storage and shipping cask designs.

The user prepares a single set of input for the control module corresponding to the type of analysis and geometric complexity of the system. The control modules use this information to derive additional parameters and prepare the input for each of the functional modules in the analytical sequence.

A number of the SCALE control modules were untested on the University of Tennessee computer system. Also, the design group was in unfamiliar territory with the use of most of the modules. Therefore, the desired codes needed to be benchmarked against reliable and similar calculations performed independently in the past. SAS3 was one such module.

3.1.1.1 SAS3 Benchmarking

SAS3 is the Shielding Analysis Sequence used to perform calculations using the MORSE-SGC (Multigroup Oak Ridge Stochastic Experiment - SuperGrouped Cross Sections) functional module.[3] MORSE is a Monte Carlo code designed to solve neutron and gamma-ray transport problems.

When used in radiation transport problems, Monte Carlo refers to the technique in which particles are individually tracked through a geometry in order to estimate the solution of the transport equation at particular points of interest. The solutions will have an associated statistical uncertainty as the tracking performed is nondeterministic. Consequently, the reliability of the resulting estimates depend both upon the accuracy of the input data (including such items as cross sections, material compositions, geometry, source characterization, etc.), and the resources committed to obtaining the answer; that is, the number of particles tracked and the effort devoted to reducing the variance of the answer. The mathematical basis for the Monte Carlo method can be found in references 8 and 9.

SAS3 also calls the functional modules BONAMI-S, NITAWL-S, and ICE-S. BONAMI performs self-shielding calculations for nuclides through the application of the Bondarenko shielding factor method.[3] NITAWL applies the Nordheim Integral technique of resonance self-shielding to nuclides that have resonance parameters associated with the cross section data. This method can account for Doppler broadening of the resonances at any temperature. NITAWL also assembles group-to-group transfer arrays from the elastic and inelastic scattering components and performs other tasks in producing a problem dependent cross section library. The two modules are called even if no resonance processing is done. Together, they convert a master library (e.g. ENDF/B-V) into a AMPX working library. ICE is used primarily to mix microscopic cross sectioned data from an AMPX working library to produce macroscopic data in one of several available

formats. ICE also interprets data in scattering transfer arrays to produce the group-to-group scattering probabilities required in Monte Carlo analysis.

Before this design project, SAS3 had not been run on the UT mainframe computer. The computer is an IBM 3081 linked to a VAXCluster.[10] In order to ensure SAS3 functioned correctly and to familiarize ourselves with this tool, a suitable calculation was chosen as a benchmark.

3.1.1.2 Benchmarking Example

An August 1991 calculation performed by Noel Cramer (ORNL) was selected as a proper benchmarking example.[6] His work involved modeling the High Flux Isotope Reactor (HFIR) spent core fuel pool storage facility to establish certain criteria for the placement of the spent cores within the storage matrix in order to minimize the radiation effects in the concrete of the pool. The facility was modeled using the MORSE code. Even though Noel Cramer's version of MORSE was different from MORSE-SGC in SAS3, a meaningful benchmark was obtained. The results of the calculations are presented in Table 3.1. Our SAS3 input files are located in Appendix C.

Table 3.1 SAS3 Benchmark

	Initial Energy Flux (MeV/cm^2s)	Initial Dose Rate (rads/s)	Statistical Uncertainty
Noel Cramer	6.880×10^{11}	368.7	~ 5%
SAS3	7.284×10^{11}	358.1	~ 10%
Percent Difference	5.87%	2.87	

For more details on the situation modeled see reference 6.

With the benchmarking of SAS3 , a tool was available that could be employed for the analysis of complex three-dimensional systems in the ANS reactor. The use of a three dimensional Monte Carlo code is very expensive, however. Compared to the one dimensional discrete ordinance transport codes, MORSE uses much more computer time - which translates directly into a higher cost in dollars due to the limitation of using a shared mainframe system as opposed to a dedicated workstation. Knowing this, our group sought to benchmark and take advantage of a 1-D discrete ordinates code in conjunction with MORSE-SGC.

3.1.2 One-Dimensional Model

A one-dimensional model was used for the majority of the test calculations where the rigor of the more complex three-dimensional model was not required. The one-dimensional model took advantage of the simple geometry and symmetry found in the spent fuel pool. An illustration of the model is given in Figure 3.1. The model used a multi-region cylindrical geometry, where the one dimension utilized was the radial distance from the origin of the mock-up being tested to the endpoint of each zone. The flux calculations within the mock-up were performed using the SAS1 SCALE control module, as described in reference 3. The SAS1 control module calls BONAMI-S and NITAWL-S to prepare the working cross-section library used in the shielding analysis. The radiation transport analysis is performed by XSDRNPM-S, a one-dimensional discrete ordinates code.

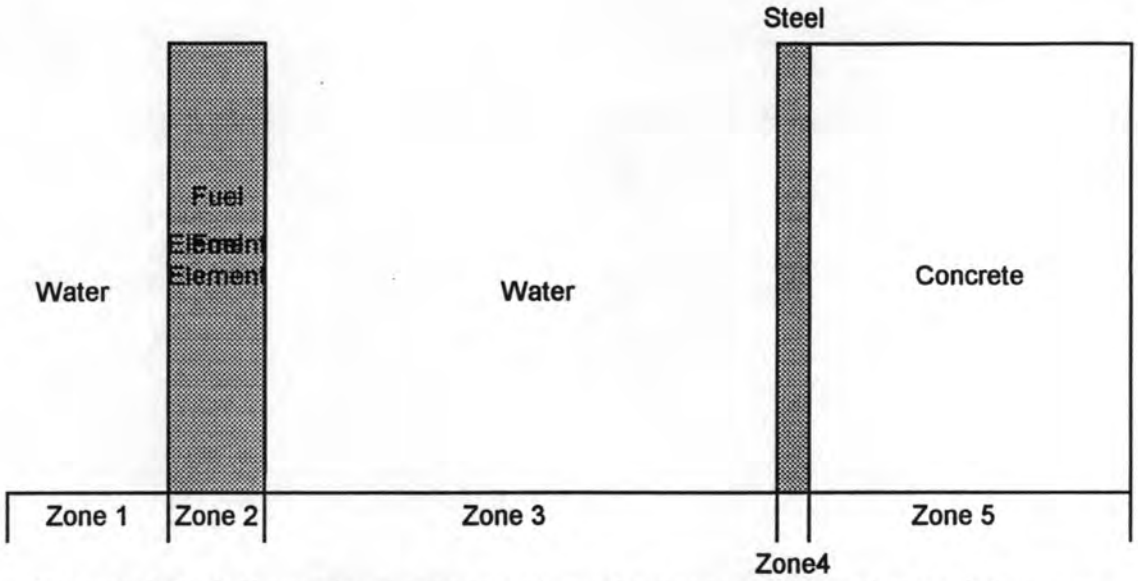


Figure 3.1 Schematic representation of a cross-sectional cut of the one-dimensional, cylindrical shell geometry model

The model in Figure 1 was utilized for the reproduction of the results obtained in the analysis of the HFIR Spent Fuel Pool.[6] This analysis was accomplished by inputting the dimensions, source spectrum and materials used in reference 6, running the code, and then comparing the output with the results given in reference 6. Specifically, the case tested was that of a single core with a one-day HFIR spent fuel decay spectrum and the HFIR spent fuel pool geometry and materials. The results of the SAS1 code could not be compared directly to those given in reference 6 because the SAS1 code will only produce dose rates in an ANSI standard material, and the calculations performed in reference 6 were for concrete. However, the results of the SAS1 run were compared to the output produced by a SAS3 code run. The SAS3 code was run to perform dose rate calculations for an ANSI standard material. The results of the SAS1 run matched those in the SAS3 run to within 10%, thereby lending credibility to the use of a one-dimensional radial model for subsequent calculations.

3.2 Modeling Current Design of the ANS Spent Fuel Pool (SFP)

Upon completion of the testing of the one and three-dimensional models for the HFIR spent fuel pool, the two models were modified for use with the ANS spent fuel pool. The three-dimensional model was used primarily to determine the effects of multiple cores within a given mock-up due to the inability of the one-dimensional model to perform such a calculation. The one-dimensional model was used to determine which materials and thicknesses of the materials would provide the greatest amount of space available for fuel elements within the pool without exceeding concrete gamma heating and dose rate limitations.

3.2.1 Modeling Current Design of ANS SFP

At the commencement of this design project, requirements existed that called for a 152.4 cm minimum distance between the spent fuel and the concrete to avoid damaging the concrete due to gamma heating from the fuel. This distance was determined based on prior HFIR calculations[6]. The water thickness in the HFIR spent fuel pool was multiplied by a factor of 2.2 to give 152.4 cm. The 2.2 factor is simply the MWD ratio of the ANSR fuel to that of the HFIR. Floor space in the ANSR containment building is very limited due to the variety of proposed activities and research that will be conducted. The space allotted for the spent cores would be consumed after 30 refueling cycles with the current 152.4 cm (5 ft) limitation. Given the short 21 day fuel cycle of the ANSR and today's problem with disposal of high level waste (i.e. there is no place to take the spent fuel and it must be stored on site in most cases), more space was needed. The ANS design team wants to safely move spent cores closer to the concrete walls so that a greater number can be stored within the pool. The first step was to verify that 152.4 cm of water between the cores and the concrete is allowable.

3.2.1 SAS3 Model

The Conceptual Design Report (CDR) for the ANSR indicates that the available space for the reactor containment building spent fuel storage pool is 4.7m x 13.1m x 11m. This allows for 30 spent cores consisting of an upper fuel element (UFE) and a lower fuel element (LFE) ranging in decay times from 21 days to 2 years. The CDR also states that the unusual storage of a core decayed for 24 hours must be safely accomplished.

3.2.1.1 Calculation Input

The calculational model of the pool storage facility and its components are shown in Figures 3.2 and 3.3. The materials are defined in Table 3.2. In this calculation the dose in the concrete was computed for the source spectrum representing the one-day decay period. The spectrum used was computed with the DKPOWR code discussed in Section 2. The core directly in front of detector #1 in Figure 3.2 was modeled with the dimensions given in Figure 3.3. The remaining cores were homogenized except that the central void region was retained for conservatism. Previous calculations indicated that homogenization of the spent cores had little effect on dose rates at the detector.[6] The source spectra below 10 keV was neglected due to the insignificant contribution to the overall dose. Activation product photons and neutrons were also disregarded because their contribution to heat in the concrete was negligible. The source photons were created isotropically in the fuel regions of the one detailed core. The photon cross section data were taken from the 18GROUPGAMMA library and processed as discussed in section 3.1.1. The concrete dose response functions are contained in Table 3.3.

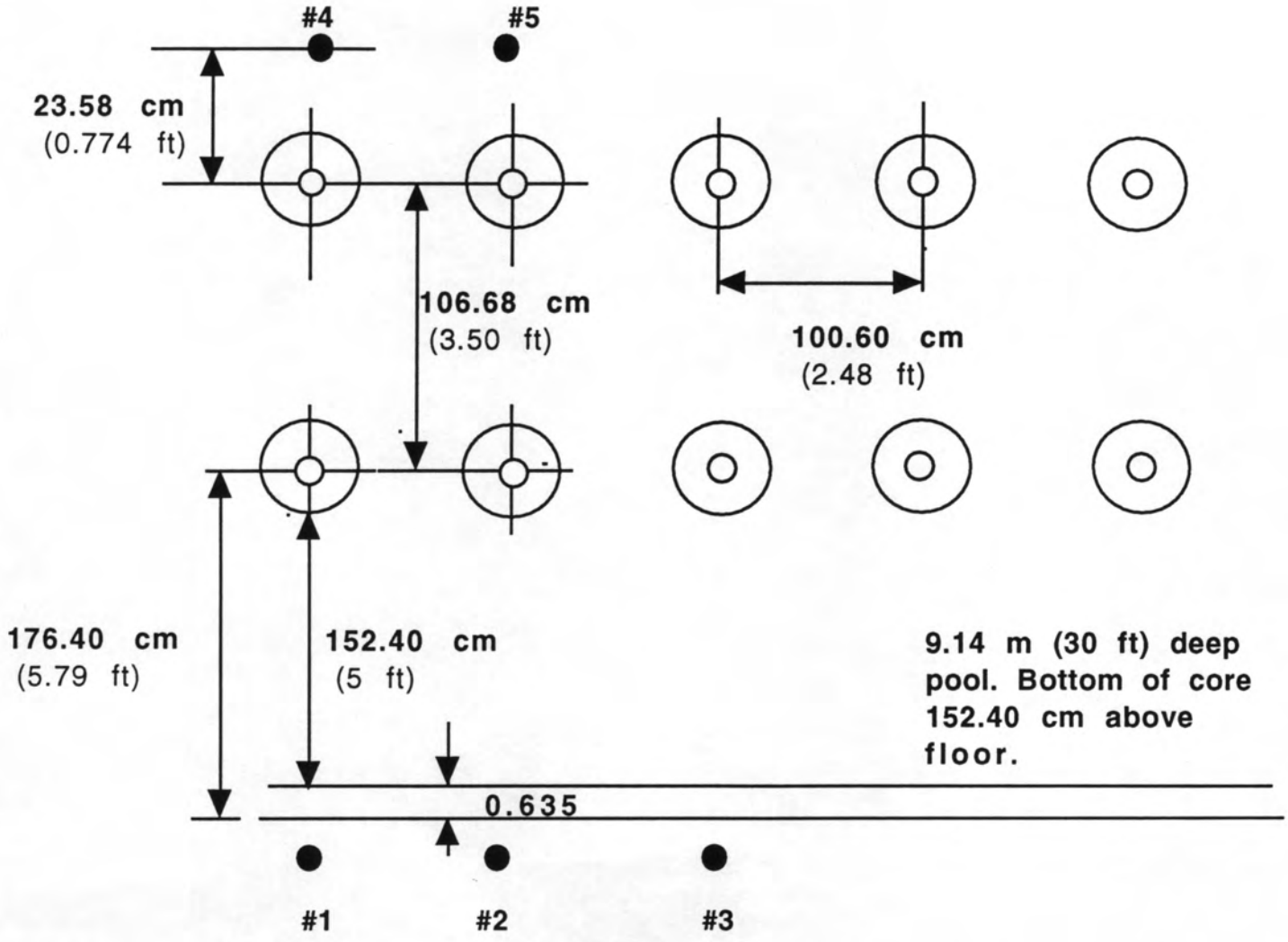


Figure 3.2 Top View of Spent Fuel Pool in Reactor Building

(Diagram not drawn to scale.)

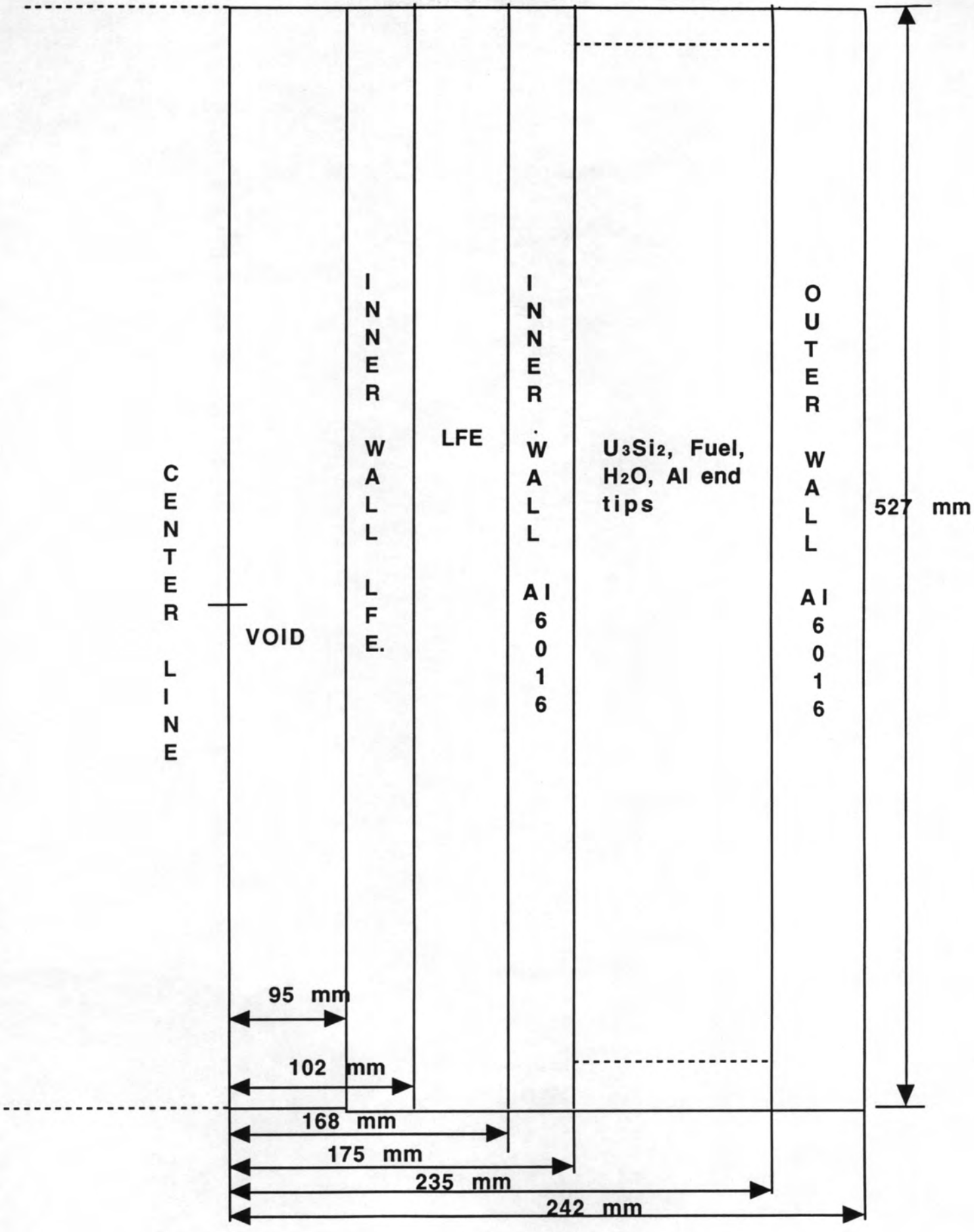


Figure 3.3 Side View of Core (Both Elements)

Table 3.2 Material Number Densities

	H_2O	Steel	Concrete	Homogenized Fuel	Al 6016
H	6.686-3[a]		1.402-2	1.000-15	
O	3.343-2		4.654-2	1.474-2	
Fe		5.9788-2	3.522-4	8.051-5	2.037-4
Cr		1.8347-2		1.250-5	6.252-5
Ni		8.125-3			
Al			1.776-3	2.791-2	5.822-2
Na			9.822-4		
Si			1.869-2	1.406-4	3.472-4
Ca			1.545-3		
Mg				1.337-4	6.687-4
Ti				1.018-5	5.092-5
Mn				1.292-5	4.438-5
U-233				1.160-15	
U-234				6.604-6	
U-235				5.823-4	
U-236				2.668-6	
U-238				3.276-5	
Cu				4.136-5	1.382-4
B_4C				1.000-15	

All values are given in units of atoms/b-cm.

[a] Read as 6.686×10^{-3}

Table 3.3 Concrete Dose Response Functions

Group	Lower Energy Boundary (MeV)	Concrete Dose Response (cm^2/g)
1	10	146250
2	8	123250
3	6.5	100625
4	5	85313
5	4	71000
6	3	59125
7	2.5	49500
8	2	44835
9	1.66	38123
10	1.33	31455
11	1	25650
12	.8	20300
13	.6	14750
14	.4	10150
15	.3	7250
16	.2	4838
17	.1	10125
18	.05	127000
	.01	

3.2.1.2 Restrictions on Heating Rates in Concretes

The concrete modeled was ordinary ASTM type O4 concrete ($\rho = 2.35$ g/cc) with the composition listed in Table 3.2. The primary radiation effect in concrete is the temperature rise due to absorbed radiation. This effect occurs at a much lower radiation level than that required to produce radiation damage.[11] An energy flux of 4×10^{10} MeV/cm^2 s produces a temperature rise on the order of 10°F in ordinary concrete.[11] This corresponds to a heat generation rate of 0.6 to 1.0 mW/cm^3 or a dose of 43.5 rads/s. Since the NRC accepts a limit of 150°F for ordinary concrete and the ambient pool temperature is given as 113°F (45°C), a limit of 4×10^{10} MeV/cm^2 s should be more than adequate. Also, a total photon dose rate of 10^{10} rads has been reported as an appropriate limit at which measurable damage occurs in concrete.[12]

3.2.1.3 Summary of Results

Only one calculation was needed to show that there is no problem with placing the spent cores 5 feet from the concrete wall. Results of the calculation follow.

- Dose Rate of 0.550 rads/s
- Initial energy flux of 1.312×10^9 MeV/cm^2 s
- Initial dose rate if all 30 cores were placed directly in front of the detector is (30)(0.550 rads/s) = 16.5 rads/s
- Two year total dose if all 30 cores were one-day decay cores for the entire two years and all were placed directly in front of the detector is (0.55 rads/s)(3600s/hr)(24 hr/day)(30 day/mo.)(24 mo.)(30) = 1.03×10^9 rads.

Obviously, there is no problem with concrete damage if 5 feet of water separates the spent cores from the concrete walls and floor. Only one core decayed for 24 hours could possibly be in this pool at one time and even that is unlikely. Moreover, dose contributions will be much less from the spent cores further away from the detectors. A 21 day old core, two rows over initially contributes only 0.0003 rads/s.

By taking into account the fact that other cores in the pool will be at some different decay period (weaker in strength than a 24 hour old core) and at larger distances from the detector, the possibility of moving the spent cores closer to the wall than 152.4 cm (5 ft) certainly exists.

3.2.1.4 Conclusions

Since none of the concrete limits (heat generation rate, total absorbed dose, or temperature rise) were exceeded with a 152.4 cm (5 ft) distance, the cores can indeed be moved nearer to the wall. By examining different types of concrete which can withstand higher temperatures and/or convect heat away faster than ordinary concrete, the amount

of water required may be reduced even further. Shielding materials interposed between the gamma ray source and the concretes should also be investigated.

3.2.2 One-Dimensional Model

The one-dimensional model was used to study the effects of materials and zone thicknesses upon the temperatures and radiation dose rates within the concrete wall. The gamma fluxes for the temperature and dose rate calculations within the concrete wall were obtained using SAS1 for a number of different mock-ups. These results were then compared to determine which set of conditions provided the optimum shielding for the ANS spent fuel pool needs. The one-dimensional model describing the ANS spent fuel pool for a given mock-up was characterized by three primary variables: thicknesses of the zones, materials present, and the decay time of the fuel element. An illustration of the model is presented in Figure 3.4.

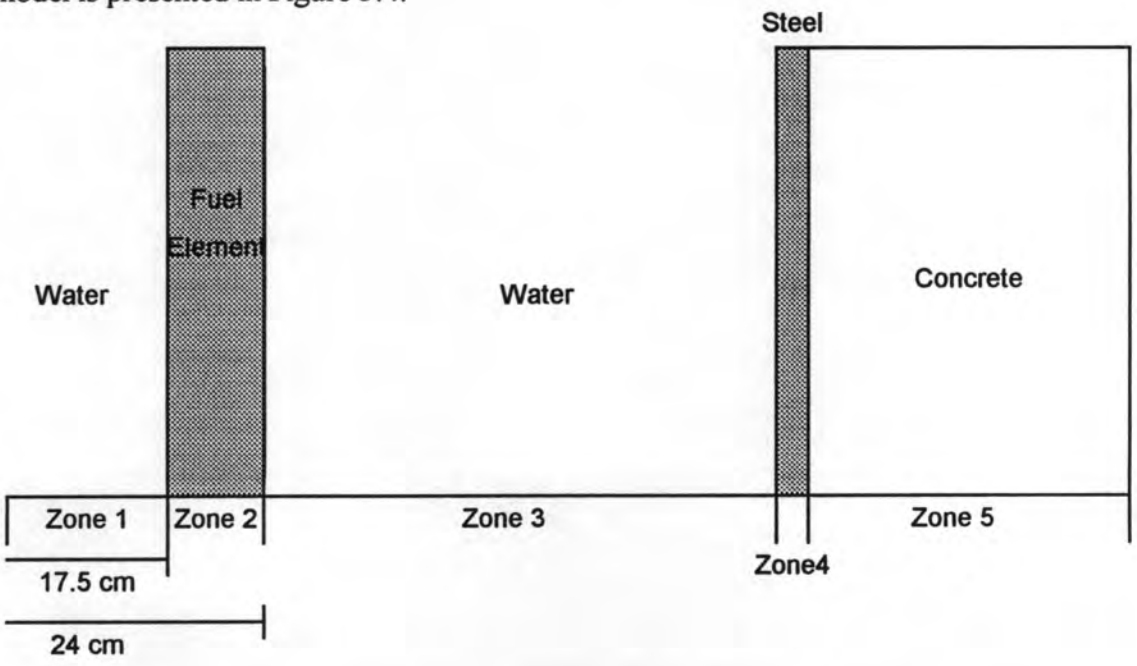


Figure 3.4 One-dimensional model for the ANS Spent fuel pool

Notice that the dimensions of zones 1 and 2 were fixed at 17.5 cm and 24 cm respectively for all of the mock-ups analyzed. These dimensions correspond to the inner and outer radii of the upper fuel element of the ANS reactor core. The dimensions of zones 3, 4, and 5 were considered variable, and were consequently changed depending upon what aspect of the spent fuel pool was being studied.

The materials that were varied in the one-dimensional mock-ups were in the steel and concrete zones. The one-dimensional model provided quick access to the relative shielding properties of a wide variety of steels and concretes. By repetition of one-dimensional model calculations, it was possible to determine which materials would perform the best under the conditions created within the mock-ups.

Two different decay spectra were used in the mock-ups. For SFP material comparisons, the DKPOWR 42-day decay spectrum was selected. This decay spectrum will be the strongest spectrum present under normal operating conditions. For material comparisons, the choice of spectrum should not have a bearing on material performance as long as the same spectrum is used consistently throughout the comparison mock-ups. For determining a recommended water thickness between the fuel and concrete, the one-day decay DKPOWR spectrum was used. The SFP has the design requirement of maintaining safe conditions in the event of an unusual occurrence, such as the placement of a one-day decayed fuel element within the SFP. Additionally, the water thickness selected as safe for a one-day decay spectrum within the SFP will apply to all other areas within the fuel transfer and storage system.

3.3 Other Problem Areas in the Refueling System

Currently in the ANSR spent fuel storage areas, locations exist where a 152.4 cm space between the spent cores and the concrete has not been maintained. Without the five foot spacing, concrete damage may occur. Modifications could be made to the design

layout that will maintain the 152.4 cm spacing without posing any additional safety risks to the facility.

3.3.1 Modeling of Current Designs

Figure 3.5 shows a sketch of the ANSR refueling system. In order to limit the dose received by the person shown in the figure, a one-day decayed fuel element would need to be transferred over the concrete dam with a clearance of only 15.2 cm. The dam has the function of maintaining a minimum safe water level (light and heavy water) within the pools in the event of a planned or unplanned draining. The elements are transferred over the dam one at a time and stored in the shown heavy water pool for two cycles (42 days). Details of the ANS refueling cycle are in reference 1. After this time, the 2-cycle decay core enters a specially designed transfer lock to be moved to the reactor containment building spent fuel storage pool. The transfer lock prevents the mixing of the light and heavy water. During the transfer, the spent cores are only a few inches above the concrete floor of the light water pool. Both of the situations would certainly result in damage to the concrete. Note that a minimum safe level (MSL) of water must be in the pools to ensure adequate shielding and cooling of the spent cores.

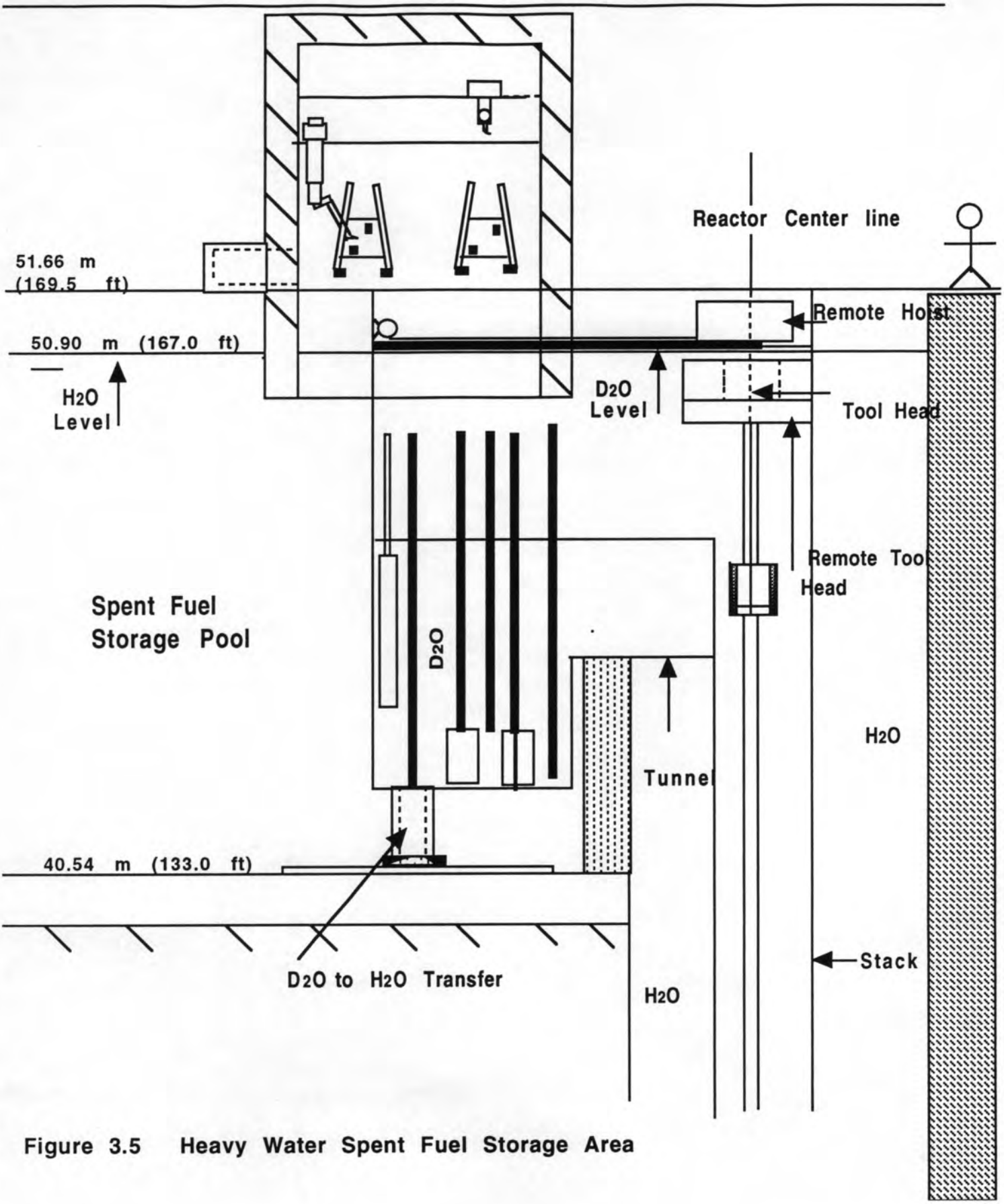


Figure 3.5 Heavy Water Spent Fuel Storage Area

4.0 Proposed Solutions to Design Issues

4.1 SAS3 Model

After it was determined that a water thickness of 152.4 cm between the spent cores and concrete walls presented no concrete damage, work could commence on moving the storage matrix closer to the pool walls.

The first calculation involved placement of the first row of spent cores 91.4 cm from the concrete. Calculational details and limits have been previously discussed in section 3.2. The approach taken was to assume that the available storage space was enlarged from 3.2 m x 11.6 m to 3.8 m x 12.2 m. The thirty cores were then evenly distributed throughout this region. This preliminary modification would of course not prove that additional cores could be stored in the pool because other issues, such as criticality safety, must be considered. A one-day decayed spent core placed in the above configuration exceeded the concrete damage limits in at least two aspects. The one-day decayed core by itself produced an energy flux in the concrete of 9.83×10^{11} MeV/cm^{2}s and a dose rate of 1192 rads/s (the limits are 4×10^{10} MeV/cm^{2}s and 43.5 rads/sec). There was no need to continue this calculation as long as only ordinary ASTM type O4 concrete and a 0.635 cm steel shield were being considered.

As the 91.4 cm distance was unacceptable, a 1.2 m thickness was tested. The geometry of the pool as modeled in MORSE-SGC is shown in Figure 4.1. The situation modeled in this calculation provided space for a 3x12 array of spent cores ranging in decay times from one day (unusual case) to 2 years. The extra 30 cm of space that was to be gained from this configuration was left to be used as desired on the right hand side of the pool.

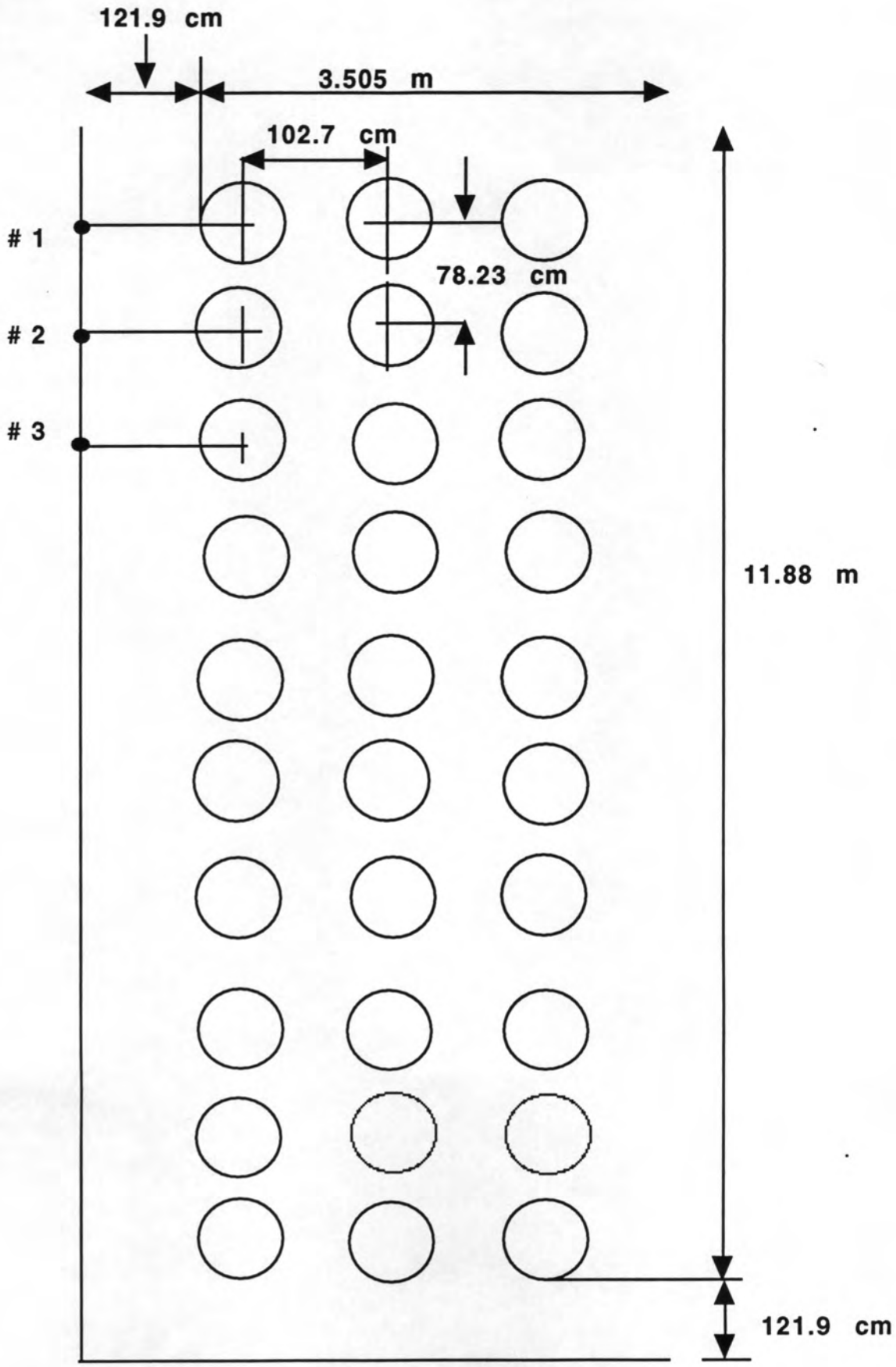


Figure 4.1 Geometry of Spent Fuel Pool (Modeled in SAS3)

4.1.2 Calculation Input

Two sets of calculations were performed. In the first set, the dose rate in the concrete wall at a position directly opposite the center of a spent core (detector #1 in Figure 4.1) was computed for source spectra representing the start of 15 decay periods. The decay intervals used are shown in Table 4.1. The core was modeled as in Figure 3.3 with the composition given in Table 3.2. The results of these calculations are in Table 4.2.

A second set of calculations was performed to determine the radiation effects at all points in question from the spent cores other than the closest core. Using the first interval spent core source, six detector locations (see Figure 4.1) were used to calculate dose and dose rates. Detector #1 is the same as for the first set of calculations. Detectors #4 and #5 were positioned so as to simulate the dose contribution from second row cores to the concrete wall. Detector #6 is directly below the source core in the concrete floor just beyond the 0.635 cm steel liner. Results from detectors #5 and #6 are conservative due to the replacement of the steel liner with water in the model.

The results of the calculations from the first interval source spectrum to each of the six detectors are given in the form of reduction factors relative to the dose for detector #1 in Table 4.3. These reduction factors can be combined with the results of the first set of calculations to determine the doses at any point in question from a first interval core anywhere in the storage matrix. The reduction factors for detectors #3, 4, and 5 can be used to account for any further distance cores not included in the calculations. Similar calculations were done for a number of other weaker source decay intervals. In each case the resulting reduction factors relative to detector #1 were greater than, but on the same order as those in Table 4.3. The Table 4.3 values can therefore be conservatively used to represent the dose reduction factors from all the source spectra.

Table 4.1 Decay Intervals

Decay Interval	Initial Time (days)	Duration (days)
1	1	1
2	2	1
3	3	1
4	4	1
5	21	17
6	42	21
7	63	21
8	84	21
9	126	42
10	180	54
11	240	60
12	300	60
13	365	65
14	548	183
15	730	183
16	913	183
17	1095	183
18	1278	183
19	1460	183
20	1643	183
21	1825	183

4.1.3 Analysis

The results of the first set of calculations are plotted in Figure 4.2. The integrated doses in Table 4.3 are obtained by assuming a straight-line (semi-log) interpolation between all dose rates in Figure 4.2. This integration procedure is conservative since the highest dose rates in Figure 4.2 will always fall below the straight-line interpolation between computed points.

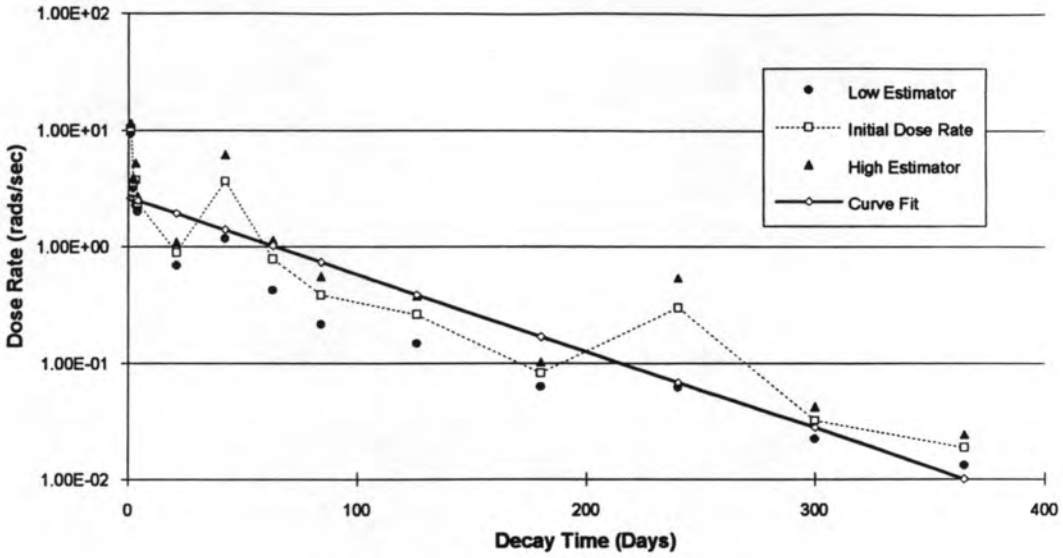


Figure 4.2 Dose Rates at Detector #1

4.1.4 Results

Using Table 4.2 and the reduction factors in Table 4.3, the dose rate and total dose over two years can now be determined for any possible (and unusual) arrangement of spent cores in the light water pool. Consider the worst case scenario as shown in Table 4.4. In this case, the initial dose rate is 10.88 rads/s and the total dose over two years is 1.69×10^7 rads. Neither of these values exceed the adopted limits for this problem. Also, the energy flux values do not exceed the limit of 4×10^{10} MeV/cm^{2}s. In conclusion, a light water thickness of 122 cm will adequately preserve integrity of the concrete walls of the pool holding a 3 by 12 array of spent fuel elements. This includes any and all unusual cores stored in this pool.

Table 4.2 Results With a Water Thickness of 122 cm

Decay Interval	Initial Energy Flux (MeV/ cm^2s)	Initial Dose Rate (rads/s)	Interval Integrated Dose (rads)	Percent of Two Year Dose**	Integrated Dose (rads)	Percent of Two Year Integrated Dose	Fractional Standard Deviation
1	2.4+10	10.4	5.51+5	3.63	5.51+55.	3.63	~0.1
2	7.85+9	3.55	2.21+5	1.46	7.71+5	5.09	~0.1
3	8.47+9	3.76	2.17+5	1.43	9.88+5	6.52	~0.4
4	5.39+9	2.358	3.23+6	21.3	4.22+6	27.83	0.156
5	2.14+9	0.891	2.99+6	19.7	7.21+6	47.57	0.220
6	8.027+9	3.703	2.17+6	14.3	9.38+6	61.91	0.686
7	1.64+9	.783	1.58+6	10.4	1.10+7	72.33	0.457
8	8.32+8	.387	1.98+6	13.1	1.29+7	85.39	0.442
9	5.346+8	.264	1.24+6	8.18	1.42+7	93.57	0.434
10	1.825+8	.0831	5.82+5	3.84	1.48+7	97.41	0.238
11	4.27+8	.302	2.34+5	1.54	1.50+7	98.95	0.793
12	7.04+7	.0322	9.83+4	.649	1.51+7	99.60	0.309
13	4.092+7	.0186	5.46+4	.360	1.51+7	99.96	0.302
14	-	-	3.39+3	.0224	1.51+7	99.98	-
15	-	-	2.50+3*	.0165	1.52+7	100.00	-

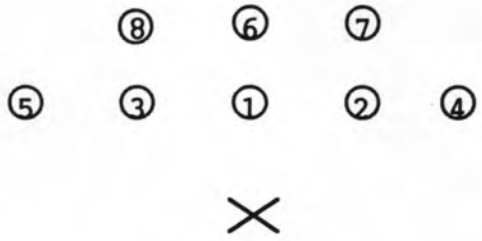
* The dose rate was assumed to remain constant in this interval

** The two year dose corresponds to that at the end of the 15th decay interval

Table 4.3 Reduction Factors

Detector	Reduction Factor
1	1.0
2	9.2
3	1000
4	12850
5	13510
6	15.3

Table 4.4 Concrete Wall Dose Rate at Detector #1



Source #	Days Decayed	Contribution to Det. #1
1	1	10.4/1.0 = 10.4
2	4	2.495/9.2 = 0.271
3	21	1.926/9.2 = 0.209
4	42	1.399/1000 = 0.0014
5	63	1.016/1000 = 0.0010
6	84	$0.738/12847 = 5.74 \times 10^{-5}$
7	126	$0.390/13510 = 2.89 \times 10^{-5}$
8	180	$.171/13510 = 1.27 \times 10^{-5}$
TOTAL		10.88 rads/s

Table 4.5 Total Dose at Detector #1 for Two Years Decay

Source #	Days Decayed	Contribution to Det #1
1	1	$1.0 \times 1.52 \times 10^7/1.0 = 1.52 \times 10^7$
2	4	$0.9348 \times 1.52 \times 10^7/9.2 = 1.54 \times 10^6$
3	21	$0.722 \times 1.52 \times 10^7/9.2 = 1.19 \times 10^5$
4	42	$.524 \times 1.52 \times 10^7/1000 = 7.97 \times 10^3$
5	63	$.381 \times 1.52 \times 10^7/1000 = 5.79 \times 10^3$
6	84	$.277 \times 1.52 \times 10^7/12847 = 3.27 \times 10^2$
7	126	$.146 \times 1.52 \times 10^7/13510 = 1.64 \times 10^2$
8	180	$.0643 \times 1.52 \times 10^7/13510 = 7.23$
TOTAL		1.69×10^7 rads

4.2 Spent Fuel Pool

The design issue associated with the spent fuel pool concerns the minimum distance required between the concrete walls and the spent fuel to maintain the integrity of the concrete. The issue was resolved by determining which materials and thicknesses of these materials would allow the least distance to be maintained between the fuel and the concrete while still maintaining reasonable costs.

4.2.1 Concrete Selection

A total of 42 different concretes were analyzed for possible use in the spent fuel pool. These concretes belonged to one of four classes: ordinary, baryte, magnetite, or limonite. Each of the concretes was tested using a mock-up with a 2-cycle (42 day) decay spectrum, 50 cm of water, and 100 cm of concrete. The eighteen group gamma fluxes were calculated for 100 mesh points within each concrete wall. Using the fluxes calculated by SAS1, the temperature profiles, temperature gradients, dose rates and heat generation rates were computed using TEMPROFV, a FORTRAN code developed in this study for one-dimensional steady state heat transfer analysis (see Appendix A). Each class of concretes displayed similar characteristics; therefore, a representative concrete was chosen from each of the classes for the final comparison. Where possible, Oak Ridge concretes were selected as the representative concrete from a given class. Also, one additional ordinary concrete was examined because of its high heat tolerance.

The following concretes were selected for the final evaluation: O3, O7, BA-OR, MA-a, and LS-a. The O3 and O7 concrete codes represent ordinary ORNL concrete and APDA high-temperature ordinary concrete, respectively. The BA-OR, MA-A, and LS-A concrete codes represent ORNL Baryte concrete, EBWR Magnetite concrete, and ANL Limonite-Steel concrete, also respectively. The temperature profiles, temperature

gradients, dose rates and heat generation rates were computed for each of the 5 concretes using the TEMPROFV code and are plotted in Figures 4.3 through 4.6.

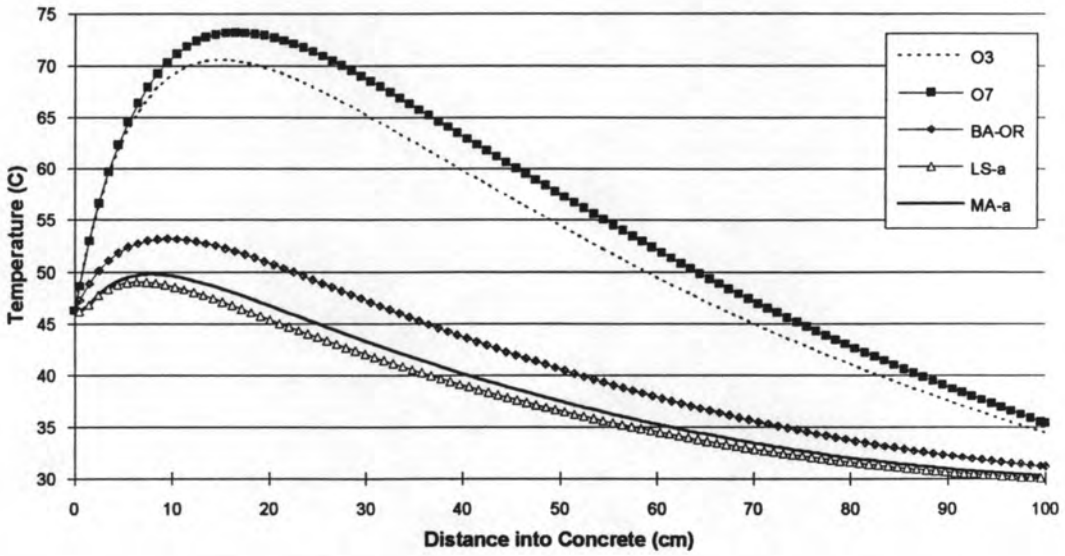


Figure 4.3 Temperature Profiles for Representative Concretes

The NRC places an upper temperature restriction of 65 °C within concrete.[11] For the mock-ups examined, the two ordinary concretes exhibit temperature profiles with temperatures that exceed this limit. The other three concretes clearly have much lower maximum temperatures in their profiles. In particular, the MA-a and LS-a concretes display the most favorable temperature profiles, with the LS-a concrete having a slight advantage.

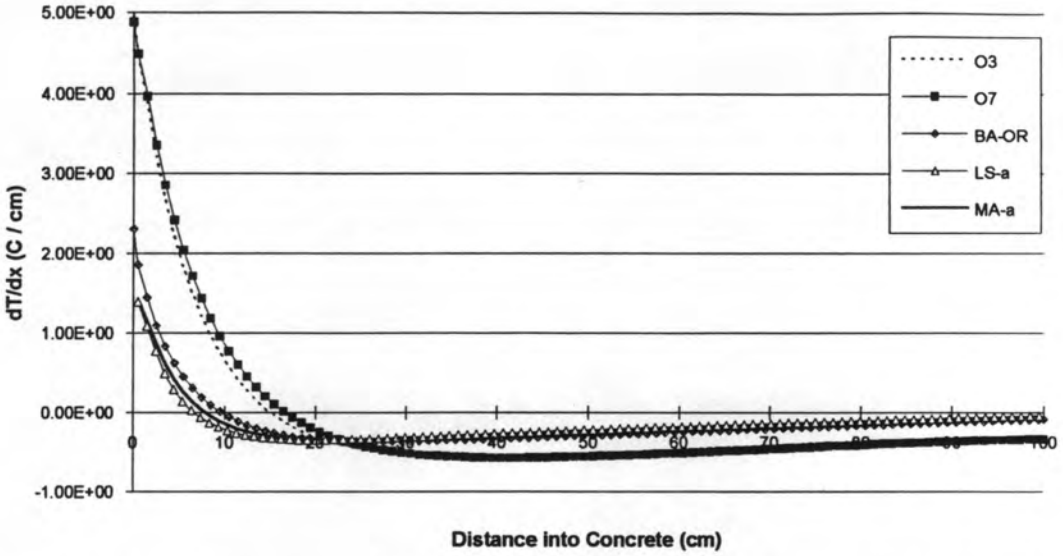


Figure 4.4 Temperature Gradient Profiles for Representative Concretes

The NRC places an upper temperature gradient restriction of 1 °C/cm within a concrete wall.[11] Under the mock-ups examined, the two ordinary concretes exhibit much higher temperature gradient profiles as compared to the other concretes. The MA-a and LS-a concretes display the smallest of temperature gradients. The fact that all of the concretes exceed the NRC restriction implies that either a shield needs to be interposed between the fuel and concrete, or the fuel must be moved further away from the concrete.

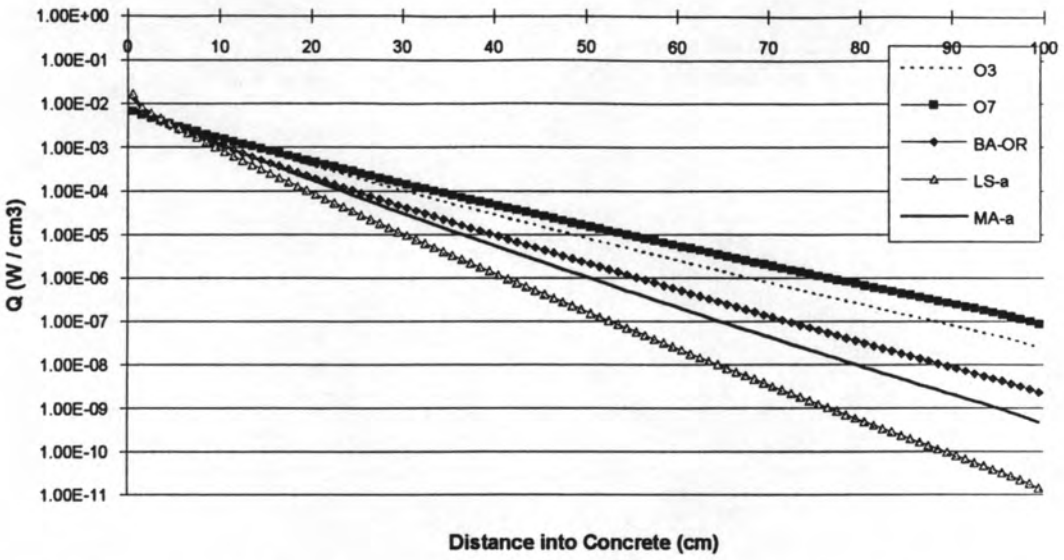


Figure 4.5 Heat Generation Rates for Representative Concretes

The NRC places an upper heat generation restriction of $1x10^{-3}$ W/cm^3 within concrete.[11] For the mock-ups examined, the concretes display a similar heat generation at the water-concrete interface, but the MA-a and LS-a concretes have much lower heat generation rates at further distances into the concrete wall. Once again, additional distance between the fuel and concrete would be needed to reduce the heat generation to an allowable limit.

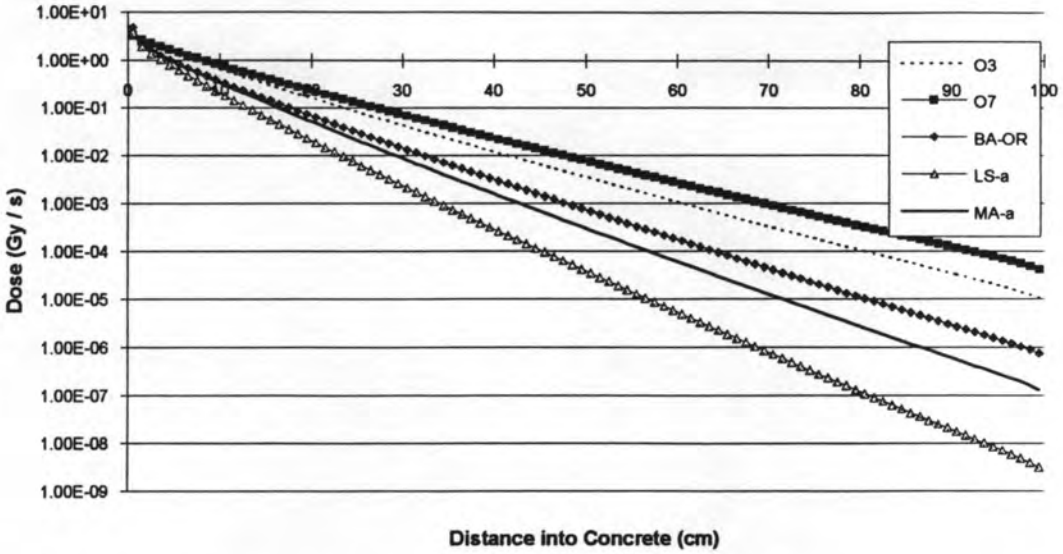


Figure 4.6 Dose Rates for Representative Concretes

The NRC places an upper dose rate restriction of 0.45 Gy/s within concrete.[11] In the mock-ups examined, the concretes absorb a comparable radiation dose at the water-concrete interface, but the MA-a and LS-a concretes experience much lower dose rates at greater distances into the concrete wall. Once again, additional distance between the fuel and concrete would be needed to reduce the heat generation to an allowable limit.

Based upon the four parameters examined, the LS-a and MA-a concretes are clearly the top contenders for use in the spent fuel pool. The cost of the LS-a concrete, however, is approximately three times that of the MA-a. The additional benefits of the LS-a concrete over the MA-a concrete do not outweigh the additional costs. The nuclear industry has already accepted MA-a concrete for use in many boiling water reactors in the United States. Since MA-a concrete is accepted as a shielding material and is cost-effective by comparison to LS-a concrete, it was selected as the concrete of choice for the SFP.

4.2.2 Steel Selection

A total of six steels were examined for possible use as a pool liner. The mock-ups used for the examination included 50 cm of water, 5.1 cm of steel, and 50 cm of O3 concrete. The steady state temperature profiles in the concrete with each of the six steels in place are given in Figure 4.7. As is apparent from the figure, the temperature profiles in the concrete do not vary significantly with the steel materials; the other regulatory constraints also displayed little deviation between materials. For this reason, it is recommended that an inexpensive stainless steel be used as a liner.

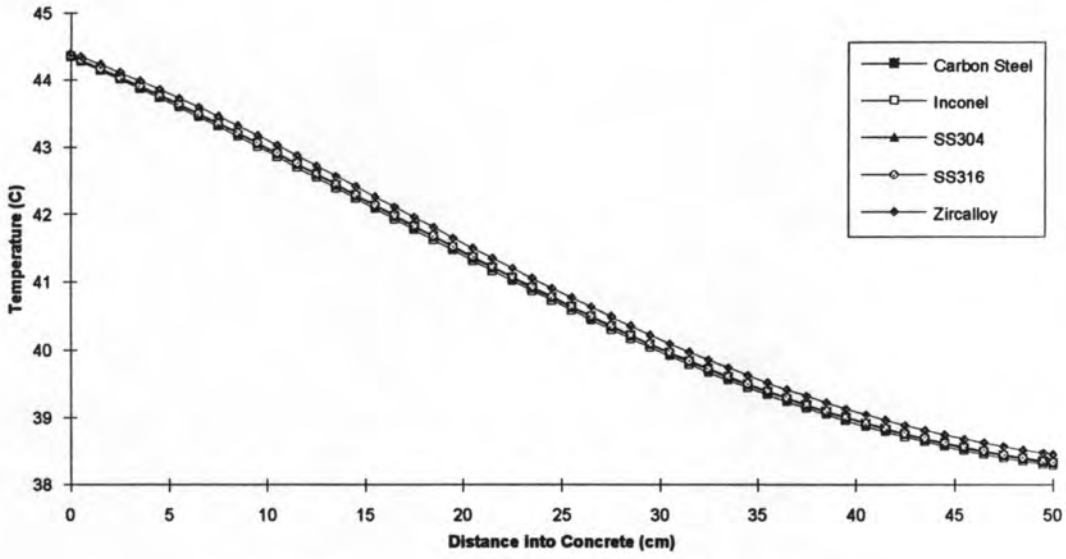


Figure 4.7 Steel Material Comparison

4.2.3 Steel Thickness Selection

Five thicknesses of steel were tested for use as a liner in the ANS spent fuel pool: 0 cm, 1.27 cm (0.5"), 2.54 cm (1"), 3.81 cm (1.5"), and 5.08 cm (2"). The model mock-ups consisted of a 2 cycle (42 day) fuel decay spectrum, 50 cm of water, and 50 cm of O3 concrete, i.e. standard ORNL concrete. The five thicknesses of steel were interposed between the water and the concrete to form five separate mock-ups. A steel thickness limit of no greater than 5.1 cm was chosen arbitrarily to keep costs of the pool shielding to

a minimum. The temperature profiles, temperature gradients, dose rates and heat generation rates were computed in the concrete for each of the 5 shield thicknesses using the TEMPROFV code and are plotted in Figures 4.8 through 4.11.

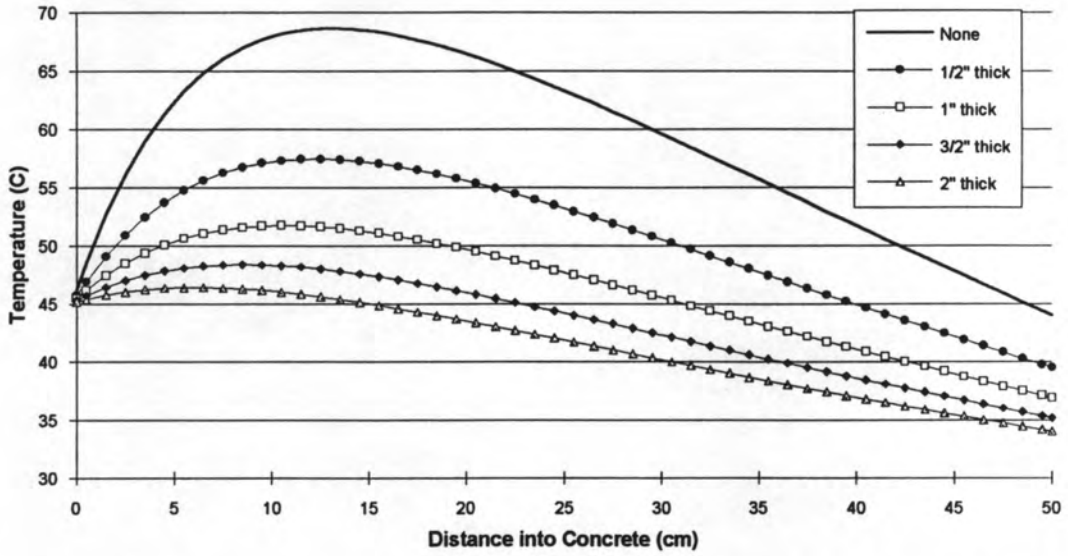


Figure 4.8 Temperature Profiles in Concrete with Various Steel Shield Thicknesses

The temperature profiles in Figure 4.8 shows a steady decrease with increasing steel thickness. A steel thickness of 5.1 cm is sufficient to prevent more than a 3 °C rise within the concrete. Any greater thickness than 5.1 cm of steel provides little return for the additional steel thickness.

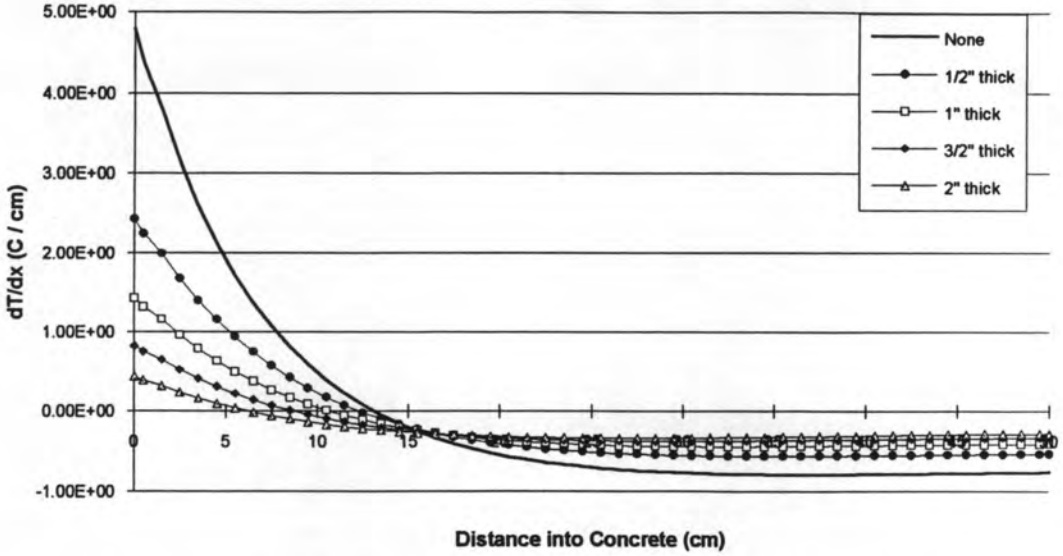


Figure 4.9 Temperature Gradient Profile in Concrete for Various Steel Shield Thicknesses

The temperature gradient profiles behaved similarly to the temperature profiles. As the steel thickness increased, the gradients became less extreme. The gradient profiles in concrete for steel shields of 3.8 cm or 5.1 cm thickness maintained a gradient of less than 1 °C/cm, the NRC limit.

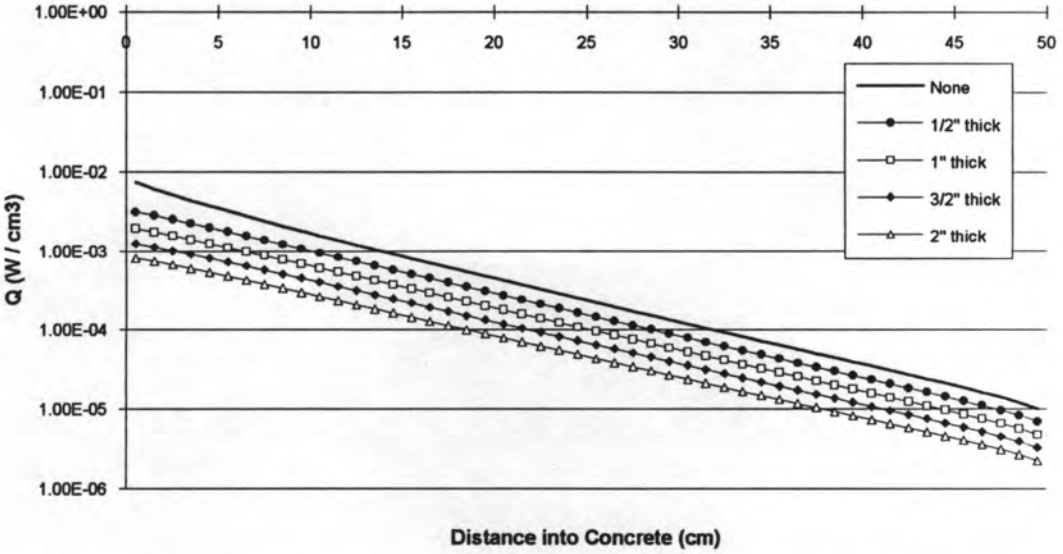


Figure 4.10 Heat Generation in Concrete for Various Steel-Shield Thicknesses

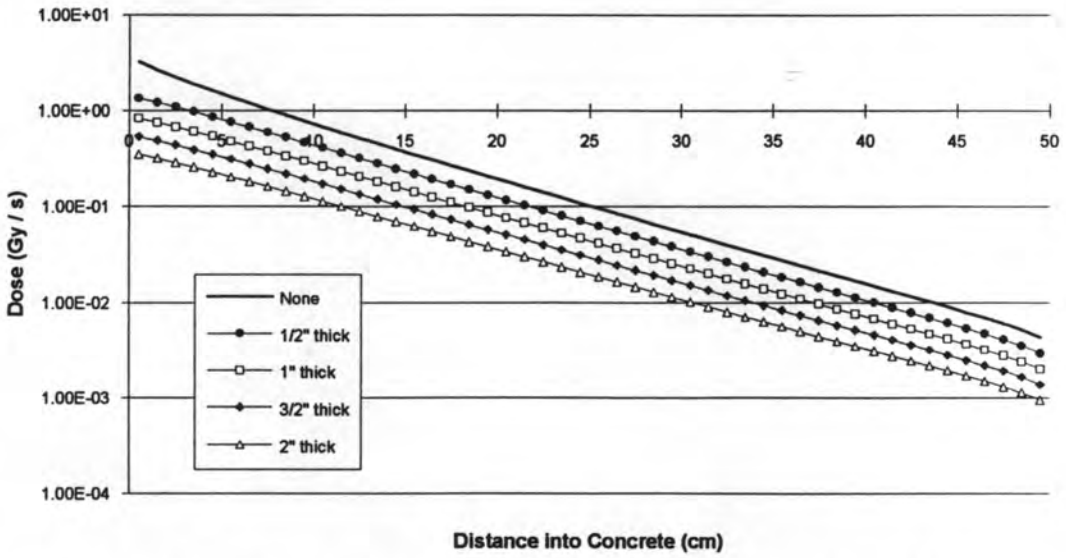


Figure 4.11 Dose Rates in Concrete for Various Steel-Shield Thicknesses

The heat generation and dose rate profiles showed a general decrease in magnitude with increasing shield thickness. Note that while several of the shield thicknesses allowed the concrete to meet the NRC restriction for dose rates, only the 5.1 cm thick steel shield held the heat generation in the concrete to less than $1x10^{-3}$ W/cm^3, the upper heat generation limit.

A shield thickness of 5.1 cm was chosen for use in the spent fuel pool. This thickness of liner maintained the ordinary concrete within all of the governing restrictions placed upon concrete by the NRC.

4.2.4 Water Thickness Selection

Once a concrete, steel, and steel liner thickness for use in the spent fuel pool were selected, the one-dimensional model was used to determine the amount of water necessary between the fuel and steel liner to maintain the concrete within the NRC regulations. Five mock-ups were utilized to make this determination. Each of the mock-ups used an ANS

upper fuel element one-day decay spectrum, 5.1 cm of steel, and 50 cm of MA-a concrete. The distances of fuel to the concrete analyzed were 50 cm, 75 cm, 80 cm, 85 cm, and 100 cm. For each of these distances, the temperature profiles, temperature gradient profiles, heat generation, and absorbed dose rate in the concrete were plotted so that a final determination could be made as to which distance would be the minimum necessary to ensure that the safety of the pool was not in question. These plots are presented in Figures 4.12 through 4.15.

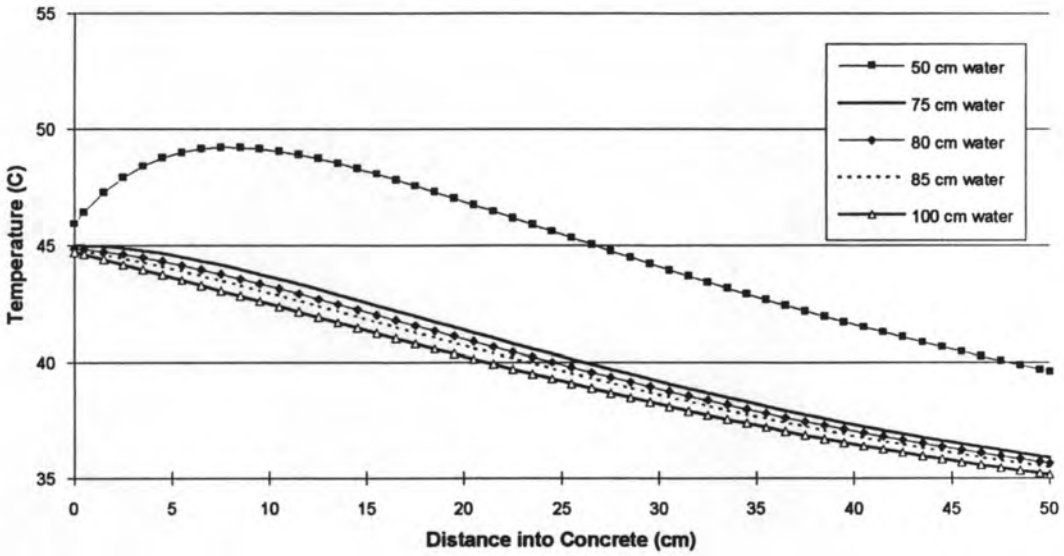


Figure 4.12 Temperature Profiles in concrete for various distances between the upper fuel element and steel liner

As can be seen from Figure 4.12, the temperature profiles in the concrete for any of the distances selected are well within the NRC guidelines. Clearly, the temperature of the concrete will not be the limiting factor in fuel element placement within the pool.

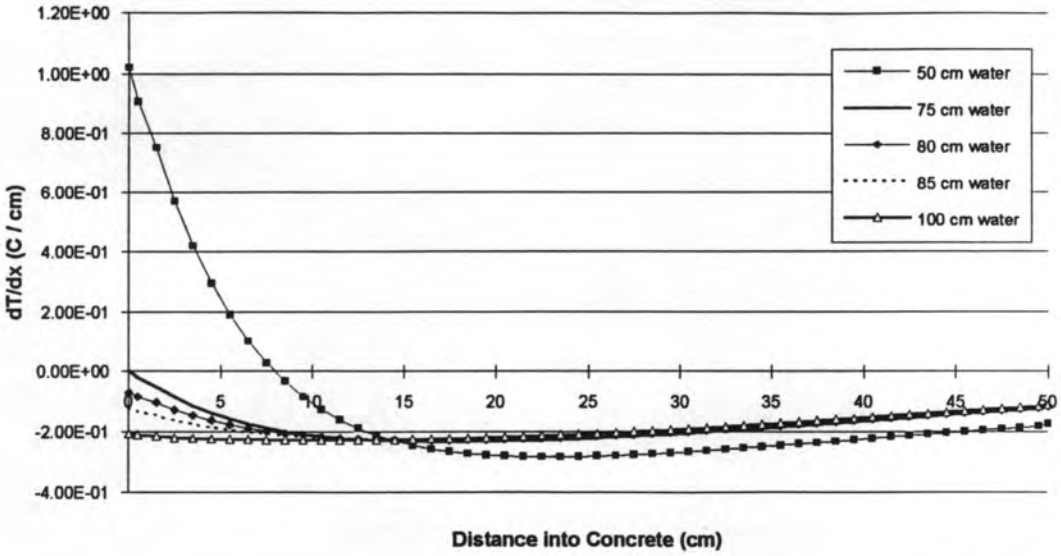


Figure 4.13 Temperature gradient profiles in concrete for various distances between the upper fuel element and steel liner

The temperature gradient profiles in Figure 4.13 eliminate the 50 cm distance from consideration; the temperature gradient for this case exceeds the NRC regulation of 1° C/cm within the concrete wall. The other distances, however, are still acceptable.

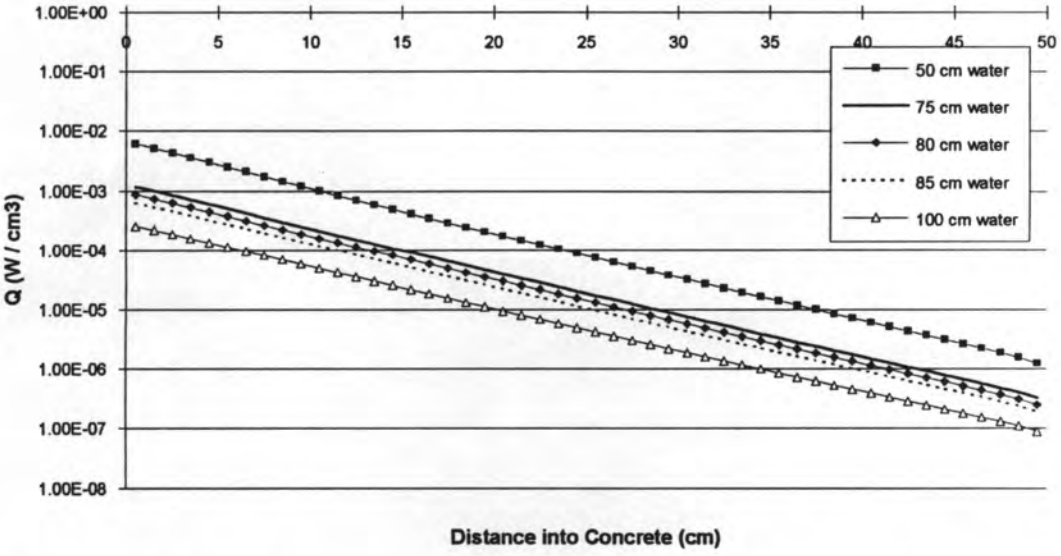


Figure 4.14 Heat generation profiles in concrete for various distances between the upper fuel element and steel liner

The NRC regulation for heat generation within concrete is an upper limit of $1x10^{-3}$ W/cm^3. The 50 cm and 75 cm distances both have heat generation values that are larger than this restriction for various positions within their heat generation profiles; consequently, only the 80 cm, 85 cm and 100 cm distances are still acceptable for consideration for use within the spent fuel pool.

The final possible restricting parameter is the absorbed radiation dose within each of the concretes.

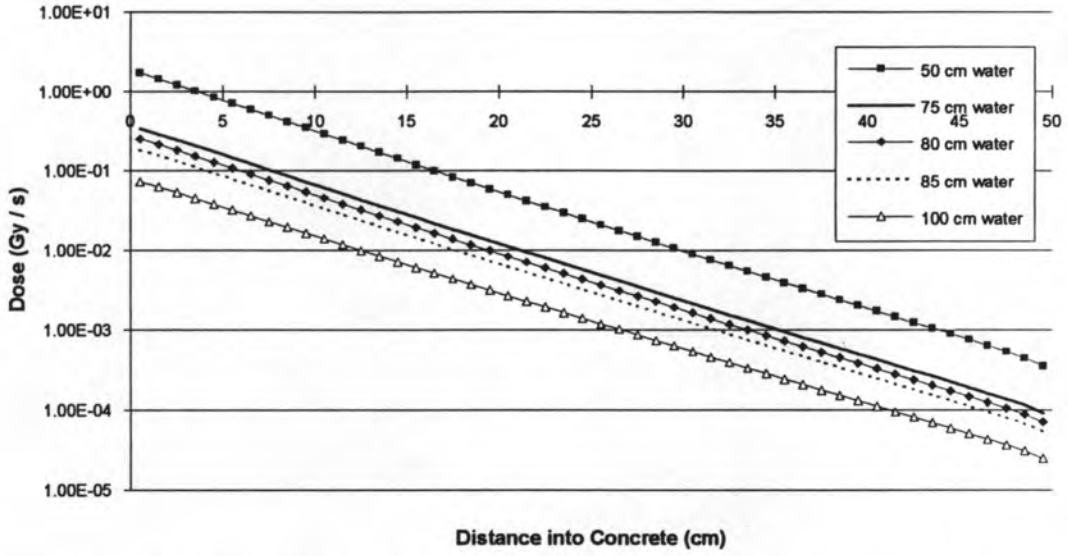


Figure 4.15 Absorbed Dose Rate Profiles in concrete for various distances between the upper fuel element and steel liner

The absorbed dose rate is not a restricting characteristic for the remaining candidate distances. The 80 cm, 85 cm, and 100 cm distances have absorbed dose rates less than the 0.45 Gy/s limit set by the NRC.

In summary, the proposed design parameters for the spent fuel pool consist of using a minimum of 80 cm of water between the fuel element and the 5.1 cm stainless steel

liner, and replacing the ordinary concrete selected for the pool with the MA-a concrete described in section 4.1.1. Additionally, a thermal analysis of the steel liner in the above configuration showed a maximum temperature rise of 2°C within the liner; thus, the steel is not considered to be placed in jeopardy. With the inclusion of these design constraints/modifications, the spent fuel pool will remain within all necessary regulations even under the unusual condition of a one-day decayed core being placed within the pool.

4.2.5 Economic Analysis of Proposed Modifications to the ANSR Spent Fuel Pool

To perform an economic analysis of the proposed modifications to the ANSR spent fuel pool, the dimensions of the pool were assumed to be 11.9 m x 4.4 m x 3.0 m. The new design suggests that the pool walls be composed of 0.92 meters of magnetite concrete with a 5.1 cm thick stainless steel shield. The 1993 cost estimate for magnetite concrete is $\$777/m^3$. Twenty nine cubic meters of concrete is needed to build the two walls closest to the spent fuel assemblies. The material cost for the magnetite concrete walls is $35,766. The additional cost of using magnetite concrete instead of ordinary concrete (material cost of $\$67/m^3$) is $32,700.

Two price estimates for stainless steel 304, the proposed material for the steel liner, are $\$20,940/m^3$ and $\$43,650/m^3$. Approximately 2.5 m^3 of steel is needed for the liner. Based on the quoted range of volumetric prices, the material cost estimates for lining the two concrete walls closest to the spent fuel assemblies are $52,904 and $110,215. The total material cost estimates for the complete design modifications are $88,670 and $145,981, depending upon which steel price is used for the estimate.

4.3 Other Areas of Concern

4.3.1 Transfer of Spent Fuel Elements Over Dam

As discussed in Section 3.3, the limiting factor in the transfer of fuel over the concrete dam is the dose received by an individual standing at the edge of the storage pool. Since a 152.4 cm (5 ft) clearance between the bottom of the fuel element and the top of the dam is assumed to be necessary to ensure the integrity of the concrete dam, calculations were performed to determine the absorbed dose rate as a function of distance between the fuel element and the water surface.

4.3.2 Calculation Input

The situation was modeled using MORSE-SGC and is displayed in Figure 4.16. The element was a one day decay, upper fuel element. The upper fuel element is the stronger of the two elements in the core since it contains 63% of the core mass.[13] Therefore calculations conducted with the upper fuel element spectrum will be conservative for the lower fuel element. The spectrum for a one day decayed core, as given by the DKPOWR code, was used in this calculation. Furthermore, the spectrum was multiplied by 0.63 to more closely represent a single upper fuel element. The material number densities for the upper fuel element are listed in Table 4.6. The stack and wall liner were included in the model, but the remote hoist and tool head equipment were omitted for simplicity (and for their negligible effect upon this model). The ANSI-prescribed photon response functions listed in Table 4.7 were used to calculate the phantom-related dose equivalents .

Table 4.6 Material Number Densities

Material	Upper Fuel Element	Heavy Water
U-233	1.000-15	
U-234	7.10-6	
U-235	6.26-4	
U-236	2.87-6	
U-238	3.52-5	
Si	4.47-4	
Mg	1.34-4	
Al	2.79-2	
Si	1.41-4	
Cr	1.25-5	
Mn	1.29-5	
Fe	8.05-5	
Cu	2.21-5	
Ti	1.02-5	
O		1.47-2
D		2.95-2
Zn	1.92-5	

All values are given in atoms/b-cm.

Table 4.7 ANSI-Prescribed Photon Response Functional Data for Phantom Related Dose Equivalents

Energy Group	Upper Energy Boundary (MeV)	Response Function (cSv cm^2)
1	10	6.1-12
2	8	6.2-12
3	6.5	8.36-11
4	5	1.39-11
5	4	1.94-11
6	3	2.59-11
7	2.5	3.36-11
8	2	4.05-11
9	1.66	5.07-11
10	1.33	5.80-11
11	1	6.62-11
12	.8	7.56-11
13	.6	8.76-11
14	.4	1.02-10
15	.3	1.20-10
16	.2	1.41-10
17	.1	1.66-10
18	.05	1.94-10
	.01	

4.3.3 Results and Conclusions

The results of the investigation are presented below in Table 4.8. The calculations show that a fuel element can be raised an additional 3 m up the stack without exposing an individual at the pool edge to more than 25 mrem/hr. This information can be used to resolve the transfer lock design issue as discussed in Section 3.3 as well as the transfer over the dam. If the top of the dam is raised to a level of 153.6 ft from 148.1 ft, the element will still clear the dam by 152.4 cm (5 ft.). With the minimum safe level now at 153.6 ft, the transfer lock and heavy water pool can be raised 152.4 cm (5 ft). and still allow for 3.7 m (12.2 ft) of heavy water to cover the fuel during a planned or unplanned pool drainage. A coverage of 3.7 m (12.2 ft) of heavy water should allow for adequate cooling of the two cores in this pool and keep the dose rate at the fuel handling cell (FHC) below 25 mrem/hr. If the transfer over the dam is attempted while the pool is drained, say in an accident situation, a person at the edge of the pool will be exposed to 150 rem/s.

Table 4.8 Dose Rates at the Pool Edge as a Function of Upper-Fuel Element Elevation

Height #	Elevation (feet)	Dose to Person (mrem/hr)	Fractional Standard Deviation
1	153.6	0.00529	.213
2	154.6	0.0175	.095
3	155.6	0.0612	.127
4	156.6	0.2238	.127
5	157.6	0.7124	.131
6	158.6	5.575	.383
7	160.6	42.45	.270

5.0 Summary and Future Work

5.1 Summary

5.1.1 Spent Fuel Pool Design Modifications

Based upon calculations performed with the one-dimensional model, the following additions and modifications are recommended for the inclusion in the design of the spent fuel pool.

1. Replace the concrete currently selected as the structural material with MA-a magnetite concrete. This concrete is easier to maintain within the regulatory limits imposed upon it within the mock-ups tested.
2. Add a 5.1 cm (2 in) steel liner along the pool wall on the concrete surface. A thickness of 5.1 cm reduces heating in the concrete by a factor of approximately 10, and reduces the maximum temperature in the concrete by a considerable margin (as high as 20°C) in the mock-ups examined. The temperature rise in the steel was calculated to be less than 2°C for a water thickness of 80 cm between a one-day decayed core and the pool liner.
3. Maintain a minimum distance of 80 cm between the fuel and the pool wall. Based upon calculations performed with one core with a one day decay spectrum, a distance of 80 cm will maintain the concrete within all applicable regulations.

5.1.2 Fuel Handling Cell Storage Pool Design Modifications

Based on calculations performed using MORSE-SGC, it was found that a fuel element could be raised an additional 3m (10 ft) while still maintaining a dose rate limit of 25 mrem/hr to a person at the FHC storage pool edge. The concrete dam can now be extended 152.4 cm (5 ft) to the elevation of 158.6 ft, and the transfer lock can be lifted to the level of 138 ft. This slight design modification will allow a five foot spacing between both the transfer lock and to the concrete floor and the fuel element and the concrete dam.

This spacing maintains a minimum safe level of water in the event of a planned or unplanned pool drainage and ensures the integrity of the concrete in these areas.

5.2 Future Work

Several areas have been identified that require work in addition to that which has been performed for this project. These areas are presented below.

5.2.1 Verify SAS1 Results Using SAS3

The concrete material, steel shield thickness, and water depth between fuel and pool walls that would allow the most space for fuel cores while still meeting the regulation limits were selected based upon one-dimensional calculations performed with the SAS1 control module. The one-dimensional model contains inherent assumptions that may produce errant results for some geometries. However, if an assumption had to be made for the model, the more conservative assumption was always selected. For verification of the results obtained from the SAS1 calculations, it is suggested that the 3-d model be used to select the final design.

5.2.2 Detailed Economic Analysis of Proposed Design Modifications

An important area of future work is to perform a more detailed economic analysis of the proposed shielding and concrete modifications than has been performed for this study. One economic area of focus is the cost of replacing the ordinary concrete in the spent fuel pool walls with MA-a concrete. The exact dimensions of the spent fuel pool and the thicknesses of the concrete need to be determined to accurately characterize the costs of the proposed design modifications. The MA-a concrete is estimated to cost approximately four times as much as a typical ordinary concrete.[11] Better cost estimates for the MA-a concrete also need to be obtained. The use of the MA-a concrete should be

required only in specific high-need areas, however. The added cost of the concrete would be justified since its use would avoid extensive redesign of the facility.

6.0 References

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Appendix A: Thermal Analysis Code TEMPROFV

A.1 Introduction

In radiation shielding situations, energy deposition by radiation within a shield can significantly raise the temperature of the shielding material. To prevent damage to a shielding material, the thermal limits of the material must not be exceeded. Hence in shielding analyses, to avoid degradation of the shield it is of interest to know not only the radiation flux in and around a shield, but also the energy deposition rate and temperature profile within a shield. To perform this thermal analysis of a shield, the FORTRAN program TEMPROFV (which stands for Temperature Profile Vax version) was developed for the 1993 University of Tennessee Nuclear Engineering Student Design Project. The program provides a one dimensional solution of the heat conduction equation in a slab shield subjected to a radiation field. TEMPROFV was developed on the PC using Microsoft FORTRAN and implemented on the UT VAX mainframe.

This appendix provides a description of the TEMPROFV computer program including the input required, the output obtained from the program, and an explanation of the mathematics employed by the program. Program verification is demonstrated by comparison of a test case with the analytical solution for that case. Finally, a listing of the program is given.

A.2 Program Description

TEMPROFV calculates a one dimensional temperature profile in a slab shield. The program has been designed for use only with output files from the 1-D discrete ordinates transport code XSDRNPM-S[3]. TEMPROFV reads the composition of the shield material used in the radiation transport calculation from the XSDRNPM-S output file. TEMPROFV then calculates the density of the shield material and the energy

dependent linear energy absorption coefficients for the shield material. Next, the scalar gamma fluxes calculated in XSDRNPM-S are folded into the response function for the absorbed dose rate. The dose rates in the slab shield are then converted to volumetric heat generation rates for the thermal analysis.

The shield is modeled as a one dimensional slab with convection boundary conditions. The fluid at the inner shield face is water and the fluid at the outer face is air. Convection boundary conditions were chosen because of their flexibility. By using a nearly infinite convection heat transfer coefficient, the convection boundary condition approaches a fixed temperature boundary condition. If the convection heat transfer coefficient is set at zero, the boundary condition becomes adiabatic, with no heat transfer. The coefficients for convective heat transfer between the shield and the fluids are calculated within the program.

TEMPROFV employs an iterative scheme for solution of the heat transfer problem. First, the one dimensional steady-state heat equation is discretized. The matrix of coefficients generated from discretization is solved using the Gauss-Seidel method[14]. After the solution has converged, the convection heat transfer coefficients and then the coefficient matrix is recalculated with the updated temperature profile. This recalculation of the matrix and solution is referred to as an outer iteration. This procedure is repeated until the differences between the temperature profiles on successive outer iterations are arbitrarily small. By employing this scheme, the heat transfer coefficients can be calculated more accurately (i.e., with the correct film temperature). After solution of the heat transfer problem is complete, the gradient of the temperature profile is calculated. Finally, the results of the calculations are output to a file.

A.2.1 Input Required

TEMPROFV requires several files for input. The file Xfer.Dat specifies the number of the zone of interest, the ambient temperature of the two fluids, and the heat

conduction coefficient of the shielding material. The gamma linear energy absorption coefficients for over 20 elements (obtained from reference 11) are given in 33 group form in the file muenrho.dat. Obviously, an XSDRNPM-S output file is also required. Aside from these files, the only other input required is that the program requests the name of the XSDRNPM-S output file from the keyboard. A sample parameter file (Xfer.Dat) is listed below:

```
Test Heat Transfer Parameters

Zone of Interest [Number]
6

Conductive Heat Transfer Coefficient for Zone of Interest [W/mC]
12.0

Inner Ambient Temperature [C]
45.0

Outer Ambient Temperature [C]
25.0
```

A.2.2 Output

TEMPROFV writes the results of its calculations to a file having the same name as the XSDRNPM-S output file, but with an extension of "T" rather than "OUTPUT." At the beginning of a temperature profile output is the name of the file followed by the contents of the parameter file. Next, the convection heat transfer coefficients calculated by the program are written. Then the maxima and minima of the temperature profile and gradient are written. Following the temperature summary information is a description of the problem geometry. Then a table lists the dose rate, heat generation rate, temperature, and temperature gradient at each mesh point. Following the temperature profile, the XSDRNPM-S input deck is echoed.

A sample output file follows:

```
CEM03.T

Test Heat Transfer Parameters

Zone of Interest [Number]
```

4

Conductive Heat Transfer Coefficient for Zone of Interest [W/mC]
.8654

Inner Ambient Temperature [C]
45.0

Outer Ambient Temperature [C]
25.0

Solution converged after 2686 iterations out of 10000 maximum and 7 outer iterations.

Inner Convective Heat Transfer Coefficient: 3.25064E+02 W / m2 C
Inner Ambient Temperature: 45.000 C
Outer Convective Heat Transfer Coefficient: 2.77198E+00 W / m2 C
Outer Ambient Temperature: 25.000 C

	Max	Xmax	Min	Xmin	Mean	Std.Dev
Temperature [C]	70.555	17	34.434	102	53.37	11.73
dT/dx [C / cm]	4.944	1	-0.549	39	-0.07	1.03

Density of Mixture 4 in Zone 4: 2.4106 g/cm3

Zone 4 ranges from r = 74.4400 cm to 174.4400 cm.
Zone 4 ranges from meshpoint 83 to 182.

I	r [cm]	Dose [Gy / s]	Q [W/cm3]	T [deg. C]	dT/dx [C / cm]
1	0.000	0.00000E+00	0.00000E+00	46.317	4.94414E+00
2	0.500	3.35023E+00	8.07616E-03	48.672	4.47701E+00
3	1.500	2.59133E+00	6.24674E-03	52.915	3.88217E+00
4	2.500	2.12714E+00	5.12773E-03	56.436	3.20405E+00
5	3.500	1.76773E+00	4.26133E-03	59.361	2.66234E+00
6	4.500	1.49502E+00	3.60393E-03	61.790	2.20785E+00
7	5.500	1.27120E+00	3.06438E-03	63.800	1.82178E+00
8	6.500	1.08938E+00	2.62609E-03	65.453	1.49177E+00
9	7.500	9.35944E-01	2.25621E-03	66.799	1.20818E+00
10	8.500	8.07450E-01	1.94646E-03	67.882	9.63778E-01
11	9.500	6.97493E-01	1.68140E-03	68.738	7.52656E-01
12	10.500	6.04059E-01	1.45616E-03	69.397	5.70077E-01
13	11.500	5.23532E-01	1.26204E-03	69.886	4.12028E-01
14	12.500	4.54576E-01	1.09581E-03	70.228	2.75164E-01
15	13.500	3.94904E-01	9.51967E-04	70.443	1.56621E-01
16	14.500	3.43569E-01	8.28217E-04	70.547	5.39722E-02
17	15.500	2.99030E-01	7.20849E-04	70.555	-3.48924E-02
18	16.500	2.60590E-01	6.28185E-04	70.481	-1.11778E-01
19	17.500	2.27175E-01	5.47633E-04	70.335	-1.78266E-01
20	18.500	1.98264E-01	4.77940E-04	70.128	-2.35734E-01
21	19.500	1.73092E-01	4.17259E-04	69.866	-2.85343E-01
22	20.500	1.51267E-01	3.64648E-04	69.559	-3.28108E-01
23	21.500	1.32238E-01	3.18776E-04	69.212	-3.64933E-01
24	22.500	1.15710E-01	2.78932E-04	68.831	-3.96580E-01
25	23.500	1.01279E-01	2.44146E-04	68.421	-4.23707E-01
26	24.500	8.87244E-02	2.13881E-04	67.985	-4.46905E-01
27	25.500	7.77496E-02	1.87425E-04	67.528	-4.66675E-01

28	26.500	6.81873E-02	1.64374E-04	67.053	-4.83431E-01
29	27.500	5.98188E-02	1.44201E-04	66.562	-4.97566E-01
30	28.500	5.25169E-02	1.26599E-04	66.058	-5.09420E-01
31	29.500	4.61193E-02	1.11176E-04	65.544	-5.19257E-01
32	30.500	4.05299E-02	9.77023E-05	65.020	-5.27327E-01
33	31.500	3.56274E-02	8.58845E-05	64.490	-5.33853E-01
34	32.500	3.13392E-02	7.55470E-05	63.953	-5.39017E-01
35	33.500	2.75742E-02	6.64711E-05	63.412	-5.42983E-01
36	34.500	2.42771E-02	5.85231E-05	62.867	-5.45901E-01
37	35.500	2.13797E-02	5.15384E-05	62.320	-5.47883E-01
38	36.500	1.88396E-02	4.54151E-05	61.772	-5.49048E-01
39	37.500	1.66051E-02	4.00287E-05	61.223	-5.49498E-01
40	38.500	1.46443E-02	3.53020E-05	60.673	-5.49303E-01
41	39.500	1.29180E-02	3.11404E-05	60.124	-5.48539E-01
42	40.500	1.14015E-02	2.74849E-05	59.576	-5.47278E-01
43	41.500	1.00653E-02	2.42637E-05	59.030	-5.45570E-01
44	42.500	8.89049E-03	2.14316E-05	58.485	-5.43468E-01
45	43.500	7.85438E-03	1.89340E-05	57.943	-5.41017E-01
46	44.500	6.94266E-03	1.67362E-05	57.403	-5.38257E-01
47	45.500	6.13799E-03	1.47964E-05	56.867	-5.35221E-01
48	46.500	5.42931E-03	1.30880E-05	56.333	-5.31942E-01
49	47.500	4.80337E-03	1.15791E-05	55.803	-5.28439E-01
50	48.500	4.25165E-03	1.02491E-05	55.276	-5.24739E-01
51	49.500	3.76400E-03	9.07360E-06	54.753	-5.20865E-01
52	50.500	3.33384E-03	8.03665E-06	54.234	-5.16841E-01
53	51.500	2.95337E-03	7.11947E-06	53.720	-5.12677E-01
54	52.500	2.61751E-03	6.30985E-06	53.209	-5.08385E-01
55	53.500	2.32026E-03	5.59328E-06	52.703	-5.03988E-01
56	54.500	2.05767E-03	4.96027E-06	52.201	-4.99490E-01
57	55.500	1.82510E-03	4.39963E-06	51.704	-4.94902E-01
58	56.500	1.61951E-03	3.90404E-06	51.211	-4.90241E-01
59	57.500	1.43732E-03	3.46483E-06	50.724	-4.85509E-01
60	58.500	1.27616E-03	3.07634E-06	50.240	-4.80715E-01
61	59.500	1.13324E-03	2.73183E-06	49.762	-4.75860E-01
62	60.500	1.00675E-03	2.42690E-06	49.289	-4.70963E-01
63	61.500	8.94517E-04	2.15634E-06	48.820	-4.66029E-01
64	62.500	7.95111E-04	1.91671E-06	48.357	-4.61052E-01
65	63.500	7.06862E-04	1.70398E-06	47.898	-4.56044E-01
66	64.500	6.28653E-04	1.51545E-06	47.445	-4.51012E-01
67	65.500	5.59179E-04	1.34797E-06	46.996	-4.45953E-01
68	66.500	4.97575E-04	1.19947E-06	46.553	-4.40880E-01
69	67.500	4.42825E-04	1.06748E-06	46.114	-4.35794E-01
70	68.500	3.94244E-04	9.50375E-07	45.681	-4.30697E-01
71	69.500	3.51046E-04	8.46240E-07	45.253	-4.25594E-01
72	70.500	3.12697E-04	7.53796E-07	44.830	-4.20487E-01
73	71.500	2.78577E-04	6.71545E-07	44.412	-4.15384E-01
74	72.500	2.48269E-04	5.98485E-07	43.999	-4.10288E-01
75	73.500	2.21291E-04	5.33449E-07	43.591	-4.05199E-01
76	74.500	1.97314E-04	4.75650E-07	43.189	-4.00120E-01
77	75.500	1.75959E-04	4.24172E-07	42.791	-3.95056E-01
78	76.500	1.56971E-04	3.78398E-07	42.399	-3.90012E-01
79	77.500	1.40050E-04	3.37608E-07	42.011	-3.84989E-01
80	78.500	1.24996E-04	3.01318E-07	41.629	-3.79996E-01
81	79.500	1.11575E-04	2.68965E-07	41.251	-3.75031E-01
82	80.500	9.96269E-05	2.40163E-07	40.879	-3.70098E-01
83	81.500	8.89686E-05	2.14470E-07	40.511	-3.65211E-01
84	82.500	7.94763E-05	1.91588E-07	40.148	-3.60377E-01
85	83.500	7.10035E-05	1.71163E-07	39.790	-3.55609E-01
86	84.500	6.34514E-05	1.52958E-07	39.437	-3.50917E-01
87	85.500	5.67066E-05	1.36698E-07	39.088	-3.46333E-01

```
 88     86.500  5.06900E-05  1.22195E-07    38.744 -3.41873E-01
 89     87.500  4.53115E-05  1.09229E-07    38.404 -3.37571E-01
 90     88.500  4.05084E-05  9.76507E-08    38.069 -3.33449E-01
 91     89.500  3.62093E-05  8.72871E-08    37.737 -3.29542E-01
 92     90.500  3.23638E-05  7.80170E-08    37.410 -3.25889E-01
 93     91.500  2.89138E-05  6.97003E-08    37.086 -3.22501E-01
 94     92.500  2.58189E-05  6.22397E-08    36.765 -3.19389E-01
 95     93.500  2.30305E-05  5.55179E-08    36.447 -3.16570E-01
 96     94.500  2.05147E-05  4.94532E-08    36.131 -3.14025E-01
 97     95.500  1.82282E-05  4.39413E-08    35.819 -3.11747E-01
 98     96.500  1.61406E-05  3.89091E-08    35.508 -3.09718E-01
 99     97.500  1.42017E-05  3.42350E-08    35.199 -3.07880E-01
100     98.500  1.23865E-05  2.98592E-08    34.892 -3.06454E-01
101     99.500  1.04716E-05  2.52432E-08    34.586 -3.04619E-01
102    100.000  0.00000E+00  0.00000E+00    34.434 -3.02193E-01


MODULE SAS1     WILL BE CALLED  TIME OF DAY 20.02.34  DATE 93.106

  18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H20,91.44CM CONCRETE (CYL)
  18GROUPGAMMA
  MULTIREGION
  '------------------------
  'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
  H2O     1                          END
  '
  U-233   2       0       1.000-15 END
  U-234   2       0       7.100-6  END
  U-235   2       0       6.260-4  END
  U-236   2       0       2.870-6  END
  U-238   2       0       3.520-5  END
  SI      2       0       4.470-4  END
  MG      2       0       1.340-4  END
  AL      2       0       2.790-2  END
  SI      2       0       1.410-4  END
  TI      2       0       1.020-5  END
  CR      2       0       1.250-5  END
  MN      2       0       1.290-5  END
  FE      2       0       8.050-5  END
  ZN      2       0       1.920-5  END
  '
  H2O     3                          END
  '
  H       4       0       1.945-2  END
  O       4       0       4.286-2  END
  C       4       0       5.914-3  END
  MG      4       0       1.412-3  END
  AL      4       0       1.897-3  END
  SI      4       0       7.329-3  END
  P       4       0       1.361-4  END
  S       4       0       1.314-4  END
  K       4       0       6.158-5  END
  CA      4       0       8.742-3  END
  FE      4       0       3.234-5  END
  NI      4       0       2.666-4  END
  '-----------------------
  END COMP
  CYLINDRICAL  END
```

```
 88     86.500  5.06900E-05  1.22195E-07    38.744 -3.41873E-01
 89     87.500  4.53115E-05  1.09229E-07    38.404 -3.37571E-01
 90     88.500  4.05084E-05  9.76507E-08    38.069 -3.33449E-01
 91     89.500  3.62093E-05  8.72871E-08    37.737 -3.29542E-01
 92     90.500  3.23638E-05  7.80170E-08    37.410 -3.25889E-01
 93     91.500  2.89138E-05  6.97003E-08    37.086 -3.22501E-01
 94     92.500  2.58189E-05  6.22397E-08    36.765 -3.19389E-01
 95     93.500  2.30305E-05  5.55179E-08    36.447 -3.16570E-01
 96     94.500  2.05147E-05  4.94532E-08    36.131 -3.14025E-01
 97     95.500  1.82282E-05  4.39413E-08    35.819 -3.11747E-01
 98     96.500  1.61406E-05  3.89091E-08    35.508 -3.09718E-01
 99     97.500  1.42017E-05  3.42350E-08    35.199 -3.07880E-01
100     98.500  1.23865E-05  2.98592E-08    34.892 -3.06454E-01
101     99.500  1.04716E-05  2.52432E-08    34.586 -3.04619E-01
102    100.000  0.00000E+00  0.00000E+00    34.434 -3.02193E-01


MODULE SAS1     WILL BE CALLED  TIME OF DAY 20.02.34  DATE 93.106

  18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H20,91.44CM CONCRETE (CYL)
  18GROUPGAMMA
  MULTIREGION
  '------------------------
  'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
  H2O     1                          END
  '
  U-233   2       0       1.000-15 END
  U-234   2       0       7.100-6  END
  U-235   2       0       6.260-4  END
  U-236   2       0       2.870-6  END
  U-238   2       0       3.520-5  END
  SI      2       0       4.470-4  END
  MG      2       0       1.340-4  END
  AL      2       0       2.790-2  END
  SI      2       0       1.410-4  END
  TI      2       0       1.020-5  END
  CR      2       0       1.250-5  END
  MN      2       0       1.290-5  END
  FE      2       0       8.050-5  END
  ZN      2       0       1.920-5  END
  '
  H2O     3                          END
  '
  H       4       0       1.945-2  END
  O       4       0       4.286-2  END
  C       4       0       5.914-3  END
  MG      4       0       1.412-3  END
  AL      4       0       1.897-3  END
  SI      4       0       7.329-3  END
  P       4       0       1.361-4  END
  S       4       0       1.314-4  END
  K       4       0       6.158-5  END
  CA      4       0       8.742-3  END
  FE      4       0       3.234-5  END
  NI      4       0       2.666-4  END
  '-----------------------
  END COMP
  CYLINDRICAL  END
```

```
      '-----------------------
      'DISTANCE FROM THE ORIGIN TO THE OUTERMOST POINT OF EACH ZONE
      1       17.5000
      2       24.0000
      3       74.4400
      4       174.4400
       END ZONE
      END

      LAST
      CONCRETE DOSE IN 91.44CM CONCRETE (CYLINDRICAL)
      CYLINDRICAL
      '
      ' THE 8TH NUMBER IS THE TOTAL SOURCE STRENGTH DIVIDED BY THE FUEL
VOLUME
      ' WHERE THE FUEL VOLUME IS 39,182 CM3 (H=46.24 CM)
      'ZONE, RADII,   MESH PTS, FUEL IDENTIFIER,OTHER INFO
      1       17.5000   18       0
      2       24.0000   14      -1              0 0 0.0  1.61220E+13
      3       74.4400   50       0
      4       174.4400 100       0
       END ZONE
      '18 GROUP GAMMA SOURCE SPECTRUM (ANS UPPER CORE) FOR DECAY OF 2
CYCLES (DKPOWR)
      '-----------------------------------------------------------------
--------
      0.000E+00    5.501E+02    9.828E+03    1.761E+12    1.528E+14
1.204E+16
      2.471E+16    2.371E+16    6.313E+17    1.375E+17    3.838E+17
1.975E+18
      1.231E+18    5.002E+17    5.002E+17    7.327E+17    6.543E+17
6.543E+17
      '0.000E+00    9.072E-05    2.791E+01    2.178E-02    1.029E+13
8.692E+14
      '1.644E+15    4.762E+13    4.565E+16    5.514E+14    1.638E+16
3.408E+17
      '9.978E+16    8.981E+15    8.981E+15    6.735E+16    2.035E+16
2.035E+16
      '-----------------------------------------------------------------
--------
      'NDETEC=? SIGNIFIES USER WILL SPECIFY DETECTOR LOCATIONS
      'NDETEC=2
      ' ID1=0 PRINTS SCALAR GAMMA FLUXES BY INTERVAL
      ID1=0
      ' NFACTR=1 SIGNALS ONE FLUX TO DOSE CONVERSION ID NUMBER TO BE
INPUT
      NFACTR=1
      ' DY=, DZ= ARE DIMENSIONS OF SLAB TO USE IN BUCKLING CORRECTION
      'DY=254.00
      'DZ=254.00
      READ XSDOSE
      '304.80CM IS THE SHIELD HEIGHT (ASSUMED TO BE 10 FEET)
      304.80
      '9504 INDICATES ANSI STANDARD GAMMA-RAY-FLUX-TO-DOSE RATE
FACTORS(RAD/HR)
      9504
      END
```

A.2.3 Theory

This section outlines the different methods employed by TEMPROFV in the sequence that they are used in the program. First, the method of cross section collapse will be addressed. Next the cross section mixing and density calculations will be described. Then the folding of the scalar flux into the response function to get dose rate and then heat generation rate will be delineated.[15] Next, calculation of the heat transfer coefficients and solution of the heat equation will be addressed. Finally, calculation of the temperature gradient will be discussed.[16]

Because linear energy absorption coefficients were readily available only in 33 group form from reference 11, the coefficients had to be collapsed into the 18 group structure of the gamma cross section library employed in XSDRNPM-S. This was done by integrating the coefficient over the energy group:

$$\left(\frac{\mu_{en}}{\rho}\right)_g = \frac{\int_{\Delta g} dE \left(\frac{\mu_{en}(E)}{\rho}\right)}{\int_{\Delta g} dE} \qquad (1)$$

which is equivalent to

$$\left(\frac{\mu_{en}}{\rho}\right)_g = \frac{\sum_g \left(\frac{\mu_{en}(E)}{\rho}\right) \Delta E}{\Delta E_g} \qquad (2)$$

where,

μ_{en}	=	linear energy absorption coefficient
ρ	=	density of the absorbing material
E	=	gamma energy
g	=	number of energy group

The cross section mixing for each energy group was accomplished with:

$$\left(\frac{\mu_{en}}{\rho}\right)_g = \frac{1}{\rho}\sum_i \left(\frac{\mu_{en}}{\rho}\right)_{g,i} \rho_i \qquad (3)$$

where ρ_i is the partial density of element i, defined by

$$\rho_i = \frac{NA_i}{N_0} \qquad (4)$$

where,

N = the number density of element i
N_O = Avagadro's number
A_i = the atomic mass of element i

To obtain the absorbed dose rate, the scalar flux obtained from XSDRNPM-S may be folded into the response function for absorbed dose rate:

$$\Re_D(E) = 1.602 \cdot 10^{-10} E\left(\frac{\mu_{en}(E)}{\rho}\right) \qquad (5)$$

where the response function for absorbed dose rate, in units of Gy cm^2 is given by,

$$\dot{D} = \int_0^\infty \Re_D(E)\phi(E) = \sum_g \Re_D(E_g)\phi_g \qquad (6)$$

where,

$\Re_D(E)$ = response function for absorbed dose rate

E = gamma energy in MeV
$\dot{D}$ = absorbed dose rate
$\phi(E)$ = gamma flux

g = number of energy group

The absorbed dose rate may be converted into a volumetric heat generation rate by multiplying by the absorbed dose rate by the density of the absorbing material:

$$\dot{q} = \dot{D}\rho \tag{7}$$

In the calculation of the heat transfer coefficients, the Grashof and Prandtl numbers must be calculated. For water, the Rayleigh number, equal to the product of the Grashof and Prandtl numbers, is given by

$$Gr\,\mathrm{Pr} = \left(\frac{g\beta\rho^2 c_p}{\mu k}\right) x^3 \Delta T \tag{8}$$

where,

x = the height of the wall

ΔT = $T_w - T_\infty$, the difference in wall and ambient temperatures

The term in parentheses can be found in tables.[16]

For air, the Grashof number is given by

$$Gr = \frac{g\beta(T_w - T_\infty)x^3}{\nu^2} \tag{9}$$

where,

g = the acceleration of gravity

β = volume coefficient of expansion, 1/T

ν = kinematic viscosity

For Rayleigh numbers ranging from 10^{-1} to 10^{12}, the Nusselt number may be calculated by:[16]

$$\overline{Nu}^{1/2} = 0.825 + \frac{0.387 Ra^{1/4}}{\left[1 + (0.492/\mathrm{Pr})^{9/16}\right]^{8/27}} \tag{10}$$

The convective heat transfer coefficient averaged over the height of the wall may be calculated from

$$\bar{h} = \frac{k}{L}\overline{Nu_L} \tag{11}$$

All of the properties are evaluated at the film temperature, T_f, given by

$$T_f = \frac{T_w + T_\infty}{2} \tag{12}$$

In Cartesian coordinates, the general heat conduction equation is given by

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \dot{q} = \rho c\frac{\partial T}{\partial \tau} \tag{13}$$

For steady-state, one dimensional heat transfer with constant thermal conductivity, the general heat conduction equation reduces to

$$\frac{d^2T}{dx^2} + \frac{\dot{q}}{k} = 0 \tag{14}$$

Convection boundary conditions are represented by

$$h_1\left(T(0) - T_{\infty 1}\right) = k\left.\frac{dT}{dx}\right|_{x=0} \tag{15}$$

$$h_2\left(T(L) - T_{\infty 2}\right) = -k\left.\frac{dT}{dx}\right|_{x=L}$$

This boundary value problem may be solved by discretizing the two differential equations. The second derivative of a function may be approximated by using a Taylor series expansion. By incorporating more of the terms into the equation, greater accuracy can be obtained. The centered finite difference approximation for the second derivative is given by

$$f''(x_i) = \frac{-f(x_{i+2}) + 16f(x_{i+1}) - 30f(x_i) + 16f(x_{i-1}) - f(x_{i-2})}{12(\Delta x)^2} \tag{16}$$

Employing (16) to discretize (14) yields the following equation for a general inner node:

$$-T(x_{i+2})+16T(x_{i+1})-30T(x_i)+16T(x_{i-1})-T(x_{i-2})=-12(\Delta x)^2\frac{q(x_i)}{k} \quad (17)$$

For the inner and outer boundary conditions, forward and backward finite difference approximations for the first derivative were employed:

$$f'(x_i)=\frac{-f(x_{i+2})+4f(x_{i+1})-3f(x_i)}{2\Delta x} \quad (18)$$

The nodal scheme is shown in Figure A.2. No heat generation is attributed to node one. In calculation of the derivatives, if a mesh point was required where a mesh point did not exist, the two surrounding mesh points were averaged to get the required temperature. By employing these techniques, the differential equation for the inner boundary condition reduces to:

$$\left(\frac{h_1\Delta x}{k}+3\right)T(1)-3.5T(2)+0.5T(3)=\frac{h_1\Delta x}{k}T_{\infty 1} \quad (19)$$

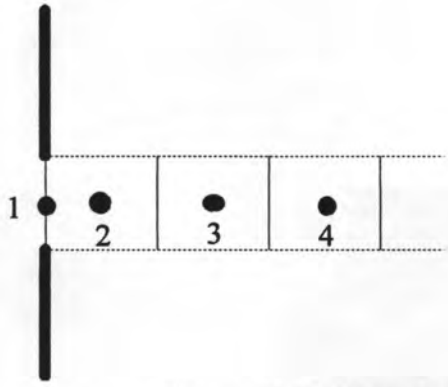


Figure A.1 Boundary Mesh Point Diagram

The matrix of coefficients generated from discretization is solved using the Gauss-Seidel method.[14] After the solution has converged, the convection heat transfer coefficients and then the coefficient matrix is recalculated with the updated temperature

profile. This recalculation of the matrix and solution is referred to as an outer iteration. This procedure is repeated until the differences between the temperature profiles at successive convergences (after each outer iteration) is arbitrarily small. By employing this scheme, the heat transfer coefficients can be calculated more accurately.

After solution of the heat transfer problem is complete, the gradient of the temperature profile is calculated using the same finite difference equations used to discretize the boundary value problem.

A.3 Program Verification

TEMPROFV was verified by comparing the solution given by the program for a spatially constant heat source with the analytical solution for the same problem. The analytical solution for the problem, solved in MathCAD is given below. Comparison of the numerical solution obtained from TEMPROFV with the analytical solution, shown in the following Microsoft Excel spreadsheet and graph demonstrate good agreement between the analytical and numerical solutions.

A.3.1 MathCAD Calculation

Analytic Solution for Constant Heat Source

$k := .120$

$L := 49.53$

$To1 := 45 \quad To2 := 25$

$h1 := 900 \cdot 10^{-4} \quad h2 := 900 \cdot 10^{-4}$

$q := .0484$

$$T1 := \frac{h2 \cdot \left(\frac{1}{2} \cdot \frac{q}{k} \cdot L^2 + To2\right) + q \cdot L + h1 \cdot To1 \cdot \left(\frac{h2 \cdot L + k}{k}\right)}{h2 + h1 \cdot \left(\frac{h2 \cdot L + k}{k}\right)} \qquad T1 = 57.80718$$

$$C1 := \frac{h1 \cdot To1 - h1 \cdot T1}{-k} \qquad C1 = 9.60538$$

$x := 0 .. L + 0.5$

$$T(x) := -\frac{q}{2 \cdot k} \cdot x^2 + C1 \cdot x + T1$$

$T(25) = 171.90011 \quad T(0) = 57.80718 \quad T(L) = 38.82895$

A.3.2 Excel Spreadsheet

hfir.T

Test Heat Transfer Parameters

Zone of Interest [Number]

6

Conductive Heat Transfer Coefficient for Zone of Interest [W/mC]

12

Inner Convective Heat Transfer Coefficient [W/m2C]

900

Inner Ambient Temperature [C]

45

Outer Convective Heat Transfer Coefficient [W/m2C]

900

Outer Ambient Temperature [C]

25

Solution converged after 1121 iterations out of 2000 maximum.

	Max	Xmax	Min	Xmin	Mean	Std.Dev
Temperature [C]	166.247	26	38.256	52	123.75	38.53
dT/dx [C / cm]	9.151	1	-9.942	52	-0.38	5.79

Density of Mixture 6 in Zone 6: 2.3204 g/cm3

Zone 6 ranges from r = 61.5950 cm to 111.1253 cm.

Zone 6 ranges from meshpoint 116 to 165.

I	r [cm]	Dose [Gy / s]	Q [W/cm3]	Numerical T [deg. C]	dT/dx [C / cm]	Analytical T(x) [deg. C]
1	0.00	0.000	0.00E+00	57.19	9.15	58.247
2	0.50	20.874	4.84E-02	61.68	8.95	62.953
3	1.49	18.873	4.84E-02	70.45	8.66	72.076

4	2.48	16.739	4.84E-02	78.83	8.26	80.803
5	3.47	14.816	4.84E-02	86.82	7.87	89.125
6	4.46	13.058	4.84E-02	94.42	7.48	97.060
7	5.45	11.496	4.84E-02	101.63	7.09	104.592
8	6.44	10.103	4.84E-02	108.46	6.70	111.735
9	7.43	8.875	4.84E-02	114.90	6.31	118.476
10	8.42	7.790	4.84E-02	120.96	5.92	124.827
11	9.41	6.838	4.84E-02	126.63	5.53	130.783
12	10.40	5.999	4.84E-02	131.92	5.15	136.337
13	11.39	5.265	4.84E-02	136.83	4.76	141.500
14	12.38	4.620	4.84E-02	141.36	4.38	146.263
15	13.37	4.055	4.84E-02	145.51	4.00	150.635
16	14.36	3.560	4.84E-02	149.28	3.61	154.610
17	15.35	3.126	4.84E-02	152.67	3.23	158.186
18	16.35	2.745	4.84E-02	155.69	2.85	161.370
19	17.34	2.412	4.84E-02	158.32	2.47	164.155
20	18.33	2.120	4.84E-02	160.58	2.09	166.547
21	19.32	1.864	4.84E-02	162.47	1.71	168.543
22	20.31	1.639	4.84E-02	163.97	1.33	170.142
23	21.30	1.442	4.84E-02	165.10	0.95	171.346
24	22.29	1.269	4.84E-02	165.86	0.57	172.153
25	23.28	1.118	4.84E-02	166.24	0.20	172.566
26	24.27	0.985	4.84E-02	166.25	-0.18	172.582
27	25.26	0.868	4.84E-02	165.88	-0.56	172.202
28	26.25	0.765	4.84E-02	165.13	-0.94	171.427
29	27.24	0.675	4.84E-02	164.01	-1.32	170.255
30	28.23	0.595	4.84E-02	162.51	-1.70	168.689
31	29.22	0.525	4.84E-02	160.64	-2.08	166.725
32	30.21	0.464	4.84E-02	158.39	-2.46	164.368
33	31.20	0.410	4.84E-02	155.76	-2.84	161.613
34	32.19	0.362	4.84E-02	152.76	-3.22	158.465
35	33.19	0.320	4.84E-02	149.38	-3.61	154.918
36	34.18	0.283	4.84E-02	145.61	-3.99	150.974
37	35.17	0.250	4.84E-02	141.47	-4.37	146.640
38	36.16	0.221	4.84E-02	136.95	-4.76	141.905
39	37.15	0.196	4.84E-02	132.05	-5.14	136.779
40	38.14	0.173	4.84E-02	126.76	-5.53	131.252
41	39.13	0.154	4.84E-02	121.10	-5.92	125.329
42	40.12	0.136	4.84E-02	115.04	-6.30	119.016
43	41.11	0.120	4.84E-02	108.61	-6.69	112.301
44	42.10	0.106	4.84E-02	101.79	-7.08	105.198
45	43.09	0.094	4.84E-02	94.58	-7.47	97.691
46	44.08	0.083	4.84E-02	86.98	-7.87	89.789
47	45.07	0.073	4.84E-02	78.99	-8.26	81.498
48	46.06	0.064	4.84E-02	70.62	-8.65	72.804
49	47.05	0.055	4.84E-02	61.85	-9.05	63.722
50	48.04	0.047	4.84E-02	52.69	-9.45	54.236
51	49.04	0.039	4.84E-02	43.13	-9.74	44.354
52	49.53	0.000	0.00E+00	38.26	-9.94	39.269

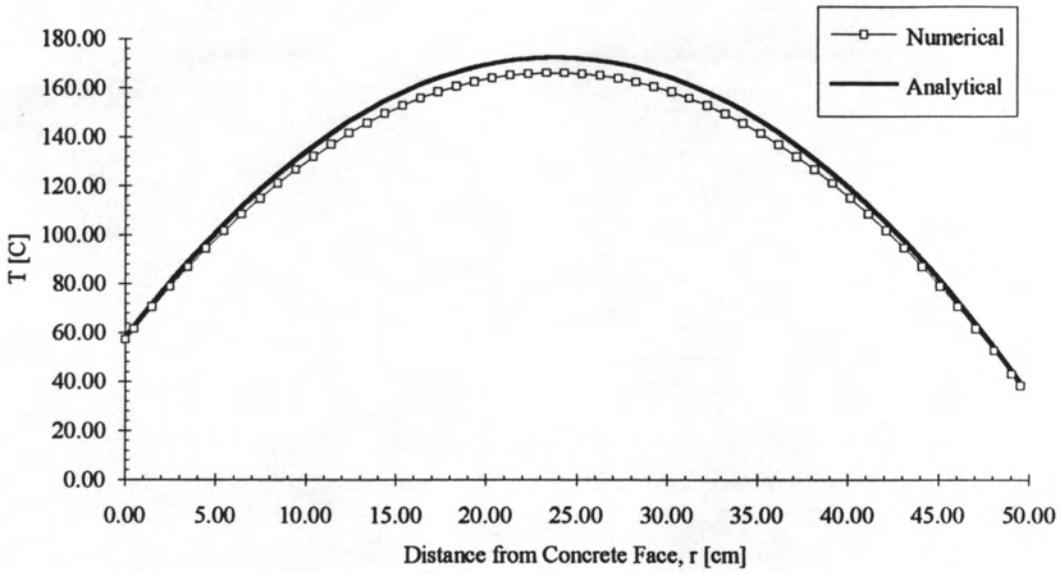


Figure A.2 Temperature Profile for Constant Heat Generation

A.4 Program Listing: TEMPROFV.FOR

```
*****************************************************************
*****************************************************************
*
      Program TemProf
*
      Implicit None
*
      Integer PFile, XFile, TFile, Kbd, Scrn, Zone, Mix, ZOIMix
      Integer Meshes, I, Z, Int, Zbndi, Zbndo, N
      Logical ReadOn, InZOI
*
      Character*30  PFile$, TFile$, XFile$
      Character*128 Line$, PLabel$, S1$, S2$
*
      Real Hi, Ho, Ti, To, k, dx
*
      Common Hi, Ho, Ti, To, k, dx, Zone, ZOIMix
*
      PFile=10
      XFile=12
      TFile=14
*
      Kbd= 5
      Scrn=6
*
      PFile$='Xfer.dat'
*
      Write (Scrn,*) 'What is the name of the XSDRN-PM output file?'
      Read (Kbd,*) XFile$
*
      Open (Unit=XFile, File=XFile$, Status='OLD')
*
      TFile$ = XFile$(1:Index(XFile$,'.'))//'T'
*
      Open (Unit=TFile, File=TFile$, Status='NEW')

*
      Write (TFile, *) TFile$
      Write (TFile, *)
*
      Write (Scrn, *)
*
 100    Format (' ','Here are the default parameters given in ', A30)
      Write (Scrn, 100) PFile$
      Write (Scrn, *)
*
      Open (PFile, File=PFile$, Status='OLD')
*
 125    Format (A75)
 130    Format (' ',A75)
*
      Do I = 1, 13
         Read (PFile, 125) Line$
         Write (TFile, 130) Line$
```

```
         Write (Scrn, 130) Line$
      End Do
*
      Rewind (PFile)
*
      Read (PFile, 125) PLabel$
      Read (PFile, 125) Line$
      Read (PFile, 125) Line$
      Read (PFile, *) Zone
      Read (PFile, 125) Line$
      Read (PFile, 125) Line$
      Read (PFile, *) k
      Read (PFile, 125) Line$
      Read (PFile, 125) Line$
      Read (PFile, *) Ti
      Read (PFile, 125) Line$
      Read (PFile, 125) Line$
      Read (PFile, *) To
*
*       Convert H-Xfer Coefficients from W/mC to W/cmC
*
      k  = k / 100.0
*
      Close (PFile)
*
      Write (Scrn, *)
*       Write (Scrn, *)
*       Write (Scrn, *) 'Use the default values (Y/N)?'
*       Read (Kbd, *) Answ$
*       Write (Scrn, *)
*
*       If ((Answ$(1:1) .NE. 'Y') .And. (Answ$(1:1) .NE. 'y')) Then
*
*          Write (Scrn, *) 'Too bad.  Change the parameter file!'
C          Write (Scrn, *) 'Change the label? [Return] for default ='
C          Write (Scrn, *) PLabel$
C          Read (Kbd, *) Line$
C          If (Line$ .NE. '') PLabel$=Line$
C       End If

C       Start reading xsdrn file
 175    Format (A128)

C       Find mixture in zone of interest

      ReadOn=.True.

      Do While (ReadOn)
         Read (XFile, 175) Line$
         If (Index(Line$, 'GEOMETRY AND MATERIAL').GT. 0)
     1        ReadOn=.False.
      End Do

      Read (XFile, 175) Line$
      Read (XFile, 175) Line$

      ZOIMix = -1
 150    Format (2X, I2, 5X, I2, A66)

      Do While (ZOIMix .LT. 0)
```

```
         Read (XFile, 150) Z, Mix, S1$
         If (Z .Eq. Zone) ZOIMix = Mix
      End Do


C       Look for number of mesh points

      ReadOn=.True.

      Do While (ReadOn)
         Read (XFile, 175) Line$
         If ((Index(Line$, 'NUMBER OF ZONES').GT. 0) .And.
     1          (Index(Line$, 'ORDER OF SCATTERING') .GT.0))
     1        ReadOn=.False.
      End Do

 200    Format (A38, I5, A66)
      Read (XFile, 200) S1$, Meshes, S2$


C       Now Pick out the boundaries on the zone of interest

      ReadOn=.True.

      Do While (ReadOn)
         Read (XFile, 175) Line$
         If (Index(Line$,'ZONE NO.       AREAS       VOLUMES').GT. 0)
     1        ReadOn=.False.
      End Do

 300    Format (1X, I4, A32, I2, A89)

      InZOI=.False.

      Do I=1, Meshes + 1
         Read (XFile, 300) Int, S1$, Z, S2$

         If ((Z .Eq. Zone) .And. (.Not. InZOI)) Then
            Zbndi = Int
            InZOI = .True.
         End If

         If ((Z .NE. Zone) .And. InZOI) Then
            Zbndo = Int - 1
            InZOI = .False.
         End If
      End Do

C       Calculate N, the length of the arrays

      N = Zbndo - Zbndi + 1 + 2

      Call Main1 (Zbndi, Zbndo, N)

      Stop
      End


*****************************************************************
*****************************************************************
```

```
      Subroutine Main1 (Zbndi, Zbndo, N)

      Implicit None

      Integer Zbndi, Zbndo, Zone, ZOIMix, N, PFile, XFile, TFile
      Integer XTmax, XTmin, XdTmax, XdTmin, I, Scrn

      Real Hi, Ho, Ti, To, k, dx, rho, L
      Real X(200), MidPt(200), Dose(200), Q(200)
      Real T(200), dTdx(200), A(200, 200+1)
      Real TMax,  TMin,  TMean,  TStDev
      Real dTMax, dTMin, dTMean, dTStDv, mu(18)

      Common Hi, Ho, Ti, To, k, dx, Zone, ZOIMix

      PFile=10
      XFile=12
      TFile=14
      Scrn = 6

      L = 10.0

      Do I = 1, N
         X(I) = 0.0
         MidPt (I) = 0.0
         Dose (I) = 0.0
         T(I) = Ti + (To - Ti) * (I-1) / N
      End Do

      T(1) = T(1) + 20
      T(N) = T(N) + 20

      Call Reader (N, Zbndi, X, MidPt)

      dx = X(3) - X(2)

      Call Matl (ZOIMix, rho, mu)

      Call FldFlx (N, Zbndi, mu, Dose)

      Call DtoQ (Dose, Q, N, rho)

C       Call Discrt (A, Q, N, T)

      Call GS (A, Q, N, N + 1, T, 1.0E-4)

      Call Derive (T, dTdx, N, dx)

      Call Analyz (T, N, TMax, XTmax, TMin, XTmin, TMean, TStDev)

      Call Analyz (dTdx, N, dTMax, XdTmax, dTMin, XdTmin,
     1             dTMean, dTStDv)


      Call Output (N, T, Tmax, XTmax, Tmin, XTmin, Tmean,
     1     Tstdev, dTdx, dTmax, XdTmax, dTmin, XdTmin, dTmean,
     1     dTstdv, rho, Zbndi, Zbndo, X, MidPt, Dose, Q)

      Close (TFile)
```

```
      Close (XFile)

      Return

      End

*****************************************************************
*****************************************************************

      Subroutine Reader (N, Zbndi, X, MidPt)

      Integer Int, I, N, Z, Zbndi
      Integer PFile, XFile, TFile

      Real X(N), MidPt(N)

      Character*60 S1$
      Character*128 Line$

      Logical ReadOn

      Common Hi, Ho, Ti, To, k, dx, Zone, ZOIMix

      PFile=10
      XFile=12
      TFile=14

 399    Format (A128)

C       Move to the geometry data

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 399) Line$
         If (Index(Line$, 'RADIUS    INT. MIDPOINT') .GT. 0)
     1        ReadOn=.False.
      End Do


C       Read Dimensions

 400    Format (I5, 6X, I2, 6X, E12.5, 1X, E12.5, A40)

      Do While (Int .LT. (Zbndi - 1))
         Read (XFile, 400) Int, Z, X(1), MidPt(1), S1$
      End Do

      I = 2
      Do While (I .LT. N)
         Read (XFile, 400) Int, Z, X(I), MidPt(I), S1$
         I = I + 1
      End Do

C       Move to Response (Reaction)

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 399) Line$
         If ((Index(Line$, 'MATERIAL').GT. 0) .And.
```

```
     1          (Index(Line$, 'REACTION') .GT.0))
     1        ReadOn=.False.
      End Do

      Read (XFile, 399) Line$


      Return

      End

******** END Subroutine Reader ******************************
*****************************************************************


      Subroutine DtoQ (Dose, Q, N, rho)

      Implicit None

      Integer I, N

      Real Dose(N), Q(N), rho

C       Converts Dose Rate in Gy / s to volumetric heat generation
C          rate in W / cm3

      Do I = 2, N -1
C        Q(I) = Dose(I) * 1.0E-3 * rho

C       Use to obtain constant heat generation
C          Q(I) = Dose(2) * 1.0E-3 * rho
C
C     Use to obtain exponentially decaying heat generation
         Q(I) = Dose(2) * exp(-0.1 * float(I-1)) * 1.0E-3 * rho

      End Do

      Return

      End

*****************************************************************
*****************************************************************


      Subroutine Derive (y, dydx, N, dx)

      Integer N, I

      Real y(N), dydx(N), dx

      dydx(1) = (-0.5*(y(2) + y(3)) + 4*y(2) - 3*y(1)) / dx

      dydx(2) = (0.5*(y(2) + y(3)) - y(1)) / dx

      dydx(3) = (y(4) - y(2)) / (2*dx)

      Do I = 4, N -3
```

```
         dydx(I) = (-y(i +2) + 8*y(i + 1) - 8*y(i-1) + y(i-2))
     1                / (12 * dx)
       End Do

       dydx(N - 2) = (y(N - 1) - y(N - 3)) / (2 * dx)

       dydx(N - 1) = (y(N) - 0.5*(y(N - 2) + y(N - 1))) / dx

       dydx(N) = (0.5*(y(N - 2) + y(N - 1)) - 4*y(N - 1)
     1            + 3*y(N)) / dx

       Return

       End

*****************************************************************
*****************************************************************


       Subroutine Discrt (A, Q, N, T)

       Integer I, J, N

       Real A(N, N + 1), Q(N), T(N), Hi, Ho, Ti, To, k, dx
       Real hWater, hAir, L

       Common Hi, Ho, Ti, To, k, dx, Zone, ZOIMix

       L = 10.0
       Do I = 1, N
          Do J = 1, N + 1
             A(I, J) = 0.0
          End Do
       End Do

       hi = hWater (T(1), Ti, L)
       ho = hAir (T(N), To, L)

C        Inner Boundary Condition

       A(1, 1) = hi * dx / k + 3.0
       A(1, 2) = -3.5
       A(1, 3) =  0.5
       A(1, N + 1) = hi * dx / k * Ti

C        First Inner Node

       A(2, 1) = 1.0
       A(2, 2) = -1.5
       A(2, 3) = 0.5
       A(2, N + 1) = -q(2) * dx**2 / (4 * k)

C        Second Inner Node

       A(3, 2) = 1.0
       A(3, 3) = -2.0
       A(3, 4) = 1.0
       A(3, N + 1) = -q(3) * dx**2 / k
```

```
      Do I = 4, N -3

C       General Inner Node

         A(I, I - 2) = -1.0
         A(I, I - 1) = 16.0
         A(I, I)     = -30.0
         A(I, I + 1) = 16.0
         A(I, I + 2) = -1.0
         A(I, N + 1) = -12 * q(i) * dx**2 / k

      End Do

C       Next to last Inner Node

      A(N - 2, N - 3) = 1.0
      A(N - 2, N - 2) = -2.0
      A(N - 2, N - 1) = 1.0
      A(N - 2, N + 1) = -q(N - 2) * dx**2 / k

C       Last Inner Node

      A(N - 1, N - 2) = 0.5
      A(N - 1, N - 1) = -1.5
      A(N - 1, N)     = 1.0
      A(N - 1, N + 1) = -q(N - 1) * dx**2 / (4 * k)

C       Outer Boundary Condition

      A(N, N - 2) =  0.5
      A(N, N - 1) = -3.5
      A(N, N)     = ho * dx / k + 3.0
      A(N, N + 1) = ho * dx / k * To

      Return

      End


**********************************************************************
**********************************************************************


      Subroutine Analyz (Y, N, Max, Xmax, Min, Xmin, Mean, StDev)

      Integer I, N, Xmax, Xmin

      Real Y(N), Max, Min, Mean, StDev, Sum

      Max = -1.E18
      Min =  1.E18
      Sum = 0.0
C       Write (6,*) 'In Analyz'

      Do I = 1, N

C          Write (6,*) I, Y(I)

         Sum = Sum + Y(I)
```

```
            If (Y(I) .GE. Max) Then
               Max = Y(I)
               Xmax = I
            End If

            If (Y(I) .LE. Min) Then
               Min = Y(I)
               Xmin = I
            End If
         End Do

C        Write (6,*) max, min
         Mean = Sum / N

         Sum = 0.0

         Do I = 1, N
            Sum = Sum + (Y(I) - Mean)**2
         End Do

         StDev = sqrt(Sum / (N - 1))

         Return

         End



*****************************************************************
*****************************************************************



********************  SUBROUTINE GS  ********************
*  This subroutine uses the Gauss-Seidel method to determine
*  the solution to a system of linear equations.
*  Adapted from pseudocode given in Chapra and Canale
*
*  Variables
*
*  A    an N by M augmented matrix containing the coefficent
*       matrix and the N by 1 column vector of constants
*  B    the N by 1 column vector of constants
*  ES   stopping epsilon
*  EA   approximate error array
*  NORMAL   a normalizing factor (elements of the
*           maindiagonal)
*  SUM  an intermediate summing variable
*  OLD  stores the old value of X(I)
*  ITER the number of iterations
*  Outer the number of outer iterations
*  FLAG a flag for stopping iteration
*  I,J  counters
*  N    the number of rows in matrix A
*  M    the number of columns in A  (M = N + 1)
*
************************************************************
```

```
      SUBROUTINE GS (A, Q, N, M, X, ES)

      Implicit None

      INTEGER  ITER, FLAG, I, J, N, M, TFile, Outer, Maxiter
      REAL     A (N, M), X(N), Q(N), ES, EA(200), OldO(200)
      REAL     NORMAL, SUM, OLD
      Logical  Reiter

      PARAMETER (MAXITER = 10000)

      TFile = 14
      ITER  = 0
      Outer = 0
 521    Continue
      FLAG  = 0
      Outer = Outer + 1

      Call Discrt (A, Q, N, X)

      DO I = 1, N
         OldO(I) = X(I)
         EA(I) = 1
         NORMAL = A(I, I)
         DO J = 1, M
            A(I, J) = A(I, J) / NORMAL
         END DO
      END DO

      DO WHILE ((ITER .LT. MAXITER) .AND. (FLAG .EQ. 0))
         FLAG = 1
         ITER = ITER + 1
C          write (TFile, *)
C          write (*, *) outer,iter

         DO I = 1, N
            OLD = X(I)
            SUM = A(I, M)
            DO J = 1, N
             IF (I .NE. J) SUM = SUM - A(I, J) * X(J)
            END DO
            X(I) = SUM
            IF (X(I) .NE. 0.0) Then
             EA(I) = ABS((X(I) - OLD) / X(I))
            Else
             EA(I) = ABS(X(I) - OLD)
            End If
         END DO

         DO I = 1, N
            IF (EA(I) .GT. ES) FLAG = 0
         END DO
      END DO

      ReIter = .False.
      Do I = 1, N
         IF (X(I) .NE. 0.0) Then
            EA(I) = ABS((X(I) - OldO(I)) / X(I))
         Else
            EA(I) = ABS(X(I) - OldO(I))
```

```
         End If

         If (EA(I) .GT. Es) ReIter = .True.
      End Do
      If (Reiter .And. (Iter .LT. MaxIter)) Goto 521

 550    Format (' ', 'Solution converged after ', I5, ' iterations'
     1         ' out of ', I5, ' maximum and ', I3,' outer iterations.')
 575    Format (' ', 'Solution not converged after ', I5,
     1         ' inner iterations with ', I3, ' outer iterations.')

      Write (TFile, *)

      If (Iter .Lt. MaxIter) Then
         Write (TFile, 550) Iter, MaxIter, Outer
      Else
         Write (TFile, 575) Iter, Outer
      End If

      Write (TFile, *)
C       Write (6,*) 'End of SR GS'

      RETURN
      END

****************** END OF SUBROUTINE GS  ******************


*****************************************************************
*****************************************************************


      Subroutine Matl (ZOIMix, rho, mu)

      Implicit None

      Integer ZOIMix, XFile, Mix, I

      Character*128 Line$, S1$, S2$
      Character*2   El$

      Real rho, N, No, mu(18), rhoj, muj(18), AtomMa

      Logical ReadOn

      Parameter (No = 6.022E23)

      XFile=12

 599    Format (A128)

      ReadOn = .True.

      Do While (ReadOn)
         Read (XFile, 599) Line$
         If (Index(Line$, '* PROBLEM COMPOSITION DESCRIPTION *')
     1        .GT. 0) ReadOn=.False.
      End Do

      Read (XFile, 599) Line$
```

```
      rho = 0.0
      Do I = 1, 18
         mu(I) = 0.0
      End Do

      ReadOn=.True.

      Do While (ReadOn)
         Read (XFile, 599) Line$
         If (Index(Line$, '* PROBLEM GEOMETRY *').GT. 0) Then
            ReadOn=.False.
         Else
            I = Index(Line$, 'SC ')
            If (I .GT. 0) Then
             El$ = Line$(I + 4:I + 5)

600     Format (A18, I2, A60)
700     Format (A9, E11.4, A60)

             Read (XFile, 600) S1$, Mix, S2$
             If (Mix .Eq. ZOIMix) Then
                Read (XFile, 700) S1$, N, S2$
                rhoj = N * 1.0E24 / No * AtomMa(El$)
                rho = rho + rhoj
                Call Getmu(El$, muj)
                Do I = 1, 18
                   mu(I) = mu(I) + muj(I) * rhoj
                End Do
             End If
            End If
         End If
      End Do

      Do I = 1, 18
         mu(I) = mu(I) / rho
      End Do

      Return

      End

******* END Subroutine Matl     ************************************
*****************************************************************


      Real Function AtomMa (El$)

      Integer Kbd, Scrn

      Character*2 El$

      AtomMa = -1.0

      Kbd = 5

      Scrn = 6

      If (El$ .Eq. 'H ') AtomMa = 1.008
```

```
      If (El$ .Eq. 'O ') AtomMa = 15.9994
      If (El$ .Eq. 'B ') AtomMa = 10.811
      If (El$ .Eq. 'C ') AtomMa = 12.01115
      If (El$ .Eq. 'NA') AtomMa = 22.990
      If (El$ .Eq. 'MG') AtomMa = 24.312
      If (El$ .Eq. 'AL') AtomMa = 26.981
      If (El$ .Eq. 'SI') AtomMa = 28.806
      If (El$ .Eq. 'P ') AtomMa = 30.974
      If (El$ .Eq. 'CL') AtomMa = 35.453
      If (El$ .Eq. 'K ') AtomMa = 39.102
      If (El$ .Eq. 'CA') AtomMa = 40.08
      If (El$ .Eq. 'TI') AtomMa = 47.90
      If (El$ .Eq. 'Mn') AtomMa = 54.938
      If (El$ .Eq. 'FE') AtomMa = 55.847
      If (El$ .Eq. 'NI') AtomMa = 58.71
      If (El$ .Eq. 'CU') AtomMa = 63.54
      If (El$ .Eq. 'V ') AtomMa = 50.942
      If (El$ .Eq. 'CR') AtomMa = 51.996
      If (El$ .Eq. 'MO') AtomMa = 95.94
      If (El$ .Eq. 'BA') AtomMa = 137.34
      If (El$ .Eq. 'S ') AtomMa = 32.064

 447    Format (' ', 'What is the atomic mass of ', A2, '?')

      If (AtomMa .LT. 0.0) Then
         Write (Scrn, 447) El$
         Read (Kbd, *) AtomMa
      End If

      Return

      End

*****************************************************************
*****************************************************************


      Subroutine Output (N, T, Tmax, XTmax, Tmin, XTmin, Tmean,
     1     Tstdev, dTdx, dTmax, XdTmax, dTmin, XdTmin, dTmean,
     1     dTstdv, rho, Zbndi, Zbndo, X, MidPt,
     1     Dose, Q)

      Implicit None

      Integer TFile, XFile, I, N, Zbndi, Zbndo, Zone, ZOIMix,
     1     XTmax, XTmin, XdTmax, XdTmin

      Real X(N), T(N), Tmax, Tmin, Tmean, Tstdev, dTdx(N), dTmax,
     1      dTmin, dTmean, dTstdv, rho, MidPt(N), Dose(N), Q(N), dx,
     1      Hi, Ho, Ti, To, k

      Logical ReadOn

      Character*128 Line$

      Common Hi, Ho, Ti, To, k, dx, Zone, ZOIMix

      XFile=12
      TFile=14
```

```
      dx = X(3) - X(2)
      MidPt(1) = MidPt(2) - dx / 2.0
      MidPt(N) = MidPt(N - 1) + dx / 2.0

      hi = hi * 1.0E4
      ho = ho * 1.0E4
  780    Format (' ','Inner Convective Heat Transfer Coefficient:  ',
     1          1P, E12.5, ' W / m2 C')

  781    Format (' ','Inner Ambient Temperature:  ', 15X, F9.3, ' C')

  782    Format (' ','Outer Convective Heat Transfer Coefficient:  ',
     1          1P, E12.5, ' W / m2 C')

  783    Format (' ','Outer Ambient Temperature:  ', 15X, F9.3, ' C')

      Write (TFile, *)
      Write (TFile, 780) hi
      Write (TFile, 781) Ti
      Write (TFile, 782) ho
      Write (TFile, 783) To
      Write (TFile, *)
      Write (TFile, *) '                          Max    Xmax      Min',
     1                 '   Xmin      Mean     Std.Dev'

  800    Format (' ', A16, F10.3, 2X, I3, 1X, F10.3, 2X,
     1        I3, 4X, F8.2, 1X, F8.2)

      Write (TFile, 800) 'Temperature [C] ', Tmax, XTMax, Tmin,
     1                    XTmin, Tmean, Tstdev

      Write (TFile, 800) 'dT/dx [C / cm]  ', dTmax, XdTMax, dTmin,
     1                    XdTmin, dTmean, dTstdv

      Write (TFile, *)

  1000   Format (' ','Density of Mixture ', I2,' in Zone ',I2,
     1        ':  ', F11.4 ' g/cm3')

  1100   Format (' ','Zone ', I2,' ranges from r = ', F12.4, ' cm  to ',
     1        F12.4, ' cm.')

  1200   Format (' ','Zone ', I2,' ranges from meshpoint ', I5, ' to ',
     1        I5,'.')

      Write (TFile, 1000) ZOIMix, Zone, rho
      Write (TFile, *)
      Write (TFile, 1100) Zone, MidPt(1), MidPt(N)
      Write (TFile, 1200) Zone, Zbndi, Zbndo

C translate X and midpoint to zero

C    Write T and dT/dx

      Write (TFile, *)
      Write (TFile, *)
      Write (TFile, *) '    I       r        Dose          Q      ',
     1                 '       T      dT/dx'
      Write (TFile, *) '          [cm]   [ Gy / s ]    [W/cm3]',
```

```
     1                    '    [deg. C]    [C / cm]'
      Write (TFile, *)

 1300   Format (' ', 2X, I3, 1X, F9.3, 1X, 1P, E12.5, 1X, 1P, E12.5,
     1         1X, 0P, F9.3, 1X, 1P, E12.5)

      Do I = 2, N
         MidPt(I) = MidPt(I) - MidPt(1)
      End Do
      MidPt(1) = 0.0

      Do I = 1, N
         Write (TFile, 1300) I, MidPt(I), Dose(I), Q(I), T(I), dTdx(I)
      End Do

      Write (TFile, *)
      Write (TFile, *)
      Write (TFile, *)

C       Move to Input Deck

 1400   Format (A128)
 1500   Format (' ', A120)

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 1400) Line$
         If (Index(Line$, 'PRIMARY MODULE ACCESS AND INPUT')
     1        .GT. 0) ReadOn=.False.
      End Do

      Read (XFile, 1400) Line$

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 1400) Line$
         If (Index(Line$, 'SECONDARY MODULE').GT. 0) Then
            ReadOn=.False.
         Else
            Write (TFile, 1500) Line$
         End If
      End Do

      Return

      End


************************************************************************
************************************************************************


      Subroutine Getmu (El$, mu)

      Implicit None

      Character*2 El$
      Character*80 Line$

      Integer muFile, I, TFile, Scrn
```

```
      Real mu33(33), mu(18)

      Logical ReadOn

      muFile = 16
      TFile = 14
      Scrn = 6

      Open (Unit = muFile, File='muenrho.dat',Status='OLD')

 100    Format (A80)
 200    Format (E13.3)
 300    Format (' ', 'Cross Section for ', A2,' not found.')
      ReadOn = .True.

      Do While (ReadOn)
         Read (mufile, 100) Line$
         If (Index(Line$, El$) .GT. 0) Then
            Do I = 1, 33
             Read (muFile, 200) mu33(I)
            End Do
            ReadOn = .False.
         End If
C        If (EOF(muFile)) Then
C           Write (TFile, 300) El$
C           Write (Scrn, 300) El$
C        End If
      End Do

      Close (muFile)

      Call C33to18 (mu33, mu)

      Return

      End

*****************************************************************
*****************************************************************


      Real Function muint(E18, E33, E, mu33)

      Real E18, E(33), mu33(33)

      Integer E33

      muint = mu33(E33) + (E18 - E(E33)) * ( (mu33(E33+1) -
     1          mu33(E33)) / (E(E33+1) - E(E33)) )

      Return

      End

*****************************************************************
*****************************************************************
```

```
      Subroutine C33to18 (mu33, mu18)

      Implicit None

      Real mu33(33), mu18(19), E(33), Sum, dE, dEg, muint

      Integer I

      Data E /0.01,0.015,0.02,0.03,0.04,0.05,0.06,0.08,
     1          0.1,0.15,0.2,0.3,0.4,0.5,0.6,0.8,1,1.5,2,
     1          3,4,5,6,8,10,15,20,30,40,50,60,80,100/

C       Group 18

      Sum = 0.0
      dE = (E(2) - E(1))/2.0
      Sum = Sum + mu33(1) * dE

      Do I = 2, 5
         dE = (E(I + 1) - E(I - 1))/2.0
         Sum = Sum + mu33(I) * dE
      End Do

      dE = (E(6) - E(5))/2.0
      Sum = Sum + mu33(6) * dE
      dEg = E(6) - E(1)
      mu18(18) = Sum / dEg

C       Group 17

      Sum = 0.0
      dE = (E(7) - E(6))/2.0
      Sum = Sum + mu33(6) * dE

      Do I = 7, 8
         dE = (E(I + 1) - E(I - 1))/2.0
         Sum = Sum + mu33(I) * dE
      End Do

      dE = (E(9) - E(8))/2.0
      Sum = Sum + mu33(9) * dE
      dEg = E(9) - E(6)
      mu18(17) = Sum / dEg

C       Group 16

      Sum = 0.0
      dE = (E(10) - E(9))/2.0
      Sum = Sum + mu33(9) * dE

      I = 10
         dE = (E(I + 1) - E(I - 1))/2.0
         Sum = Sum + mu33(I) * dE

      dE = (E(11) - E(10))/2.0
      Sum = Sum + mu33(11) * dE
      dEg = E(11) - E(9)
      mu18(16) = Sum / dEg
```

```
C       Group 15

        mu18(15) = (mu33(11) + mu33(12)) / 2.0

C       Group 14

        mu18(14) = (mu33(13) + mu33(12)) / 2.0

C       Group 13

        Sum = 0.0
        dE = (E(14) - E(13))/2.0
        Sum = Sum + mu33(13) * dE

        I = 14
           dE = (E(I + 1) - E(I - 1))/2.0
           Sum = Sum + mu33(I) * dE

        dE = (E(15) - E(14))/2.0
        Sum = Sum + mu33(15) * dE
        dEg = E(15) - E(13)
        mu18(13) = Sum / dEg

C       Group 12
        mu18(12) = (mu33(15) + mu33(16)) / 2.0

C       Group 11
        mu18(11) = (mu33(16) + mu33(17)) / 2.0

C       Group 10
        mu18(10) = (mu33(17) + muint(1.3, 17, E, mu33)) / 2.0

C       Group 9
        mu18(9) = (muint(1.3, 17, E, mu33) +
       1             muint(1.7, 18, E, mu33)) / 2.0

C       Group 8
        mu18(8) = (muint(1.7, 18, E, mu33) + mu33(19)) / 2.0

C       Group 7
        mu18(7) = (mu33(19) + muint(2.5, 19, E, mu33)) / 2.0

C       Group 6
        mu18(6) = (muint(2.5, 19, E, mu33) + mu33(20)) / 2.0

C       Group 5
        mu18(5) = (mu33(20) + mu33(21)) / 2.0

C       Group 4
        mu18(4) = (mu33(21) + mu33(22)) / 2.0

C       Group 3
        mu18(3) = (mu33(22) + muint(6.5, 23, E, mu33)) / 2.0

C       Group 2
        mu18(2) = (muint(6.5, 23, E, mu33) + mu33(24)) / 2.0

C       Group 1
        mu18(1) = (mu33(24) + mu33(25)) / 2.0
```

```
      Return
      End

************************************************************
************************************************************

      Subroutine FldFlx (N, Zbndi, mu, Dose)

      Implicit None

      Integer I, J, N, Zbndi, XFile, TFile, PFile, Int, Scrn

      Real mu(18), Dose(N), Flux(18), E18(19)

      Character*128 Line$

      Logical ReadOn

      Data E18 / 1.00E+07,8.00E+06,6.50E+06,5.00E+06,4.00E+06,
     1           3.00E+06,2.50E+06,2.00E+06,1.70E+06,1.30E+06,
     1           1.00E+06,8.00E+05,6.00E+05,4.00E+05,3.00E+05,
     1           2.00E+05,1.00E+05,5.00E+04,1.00E+04 /

      PFile=10
      XFile=12
      TFile=14
      Scrn = 6

C       Convert Energies from eV to MeV

      Do I = 1, 19
         E18(I) = E18(I) * 1.0E-6
      End Do

 100    Format (A128)

      Rewind (XFile)

C       Move to the geometry data

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 100) Line$
         If (Index(Line$, 'RADIUS    INT. MIDPOINT') .GT. 0)
     1        ReadOn=.False.
      End Do

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 100) Line$
         If (Index(Line$, 'TOTAL FLUX') .GT. 0)
     1        ReadOn=.False.
      End Do

      Read (XFile, 100) Line$
      Read (XFile, 100) Line$

      Do I = 1, N
```

```
         Dose(I) = 0.0
      End Do

C       Read Flux for Groups 1 through 8

 200    Format (1X, I4, 8(1X, E12.5))

      Int = 0

      Do While (Int .LT. (Zbndi - 1))
         Read (XFile, 200) Int, (Flux(J), J = 1, 8)
      End Do

      I = 2
      Do While (I .LE. (N - 1))
         Read (XFile, 200) Int, (Flux(J), J = 1, 8)
         Do J = 1, 8
            Dose(I) = Dose(I) + 1.602E-10 * (E18(J) + E18(J+1))
     1                  / 2.0 * mu(J) * Flux(J)
         End Do
         I = I + 1
      End Do


C       Read Flux for Groups 9 through 16

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 100) Line$
         If (Index(Line$, 'GRP.  9') .GT. 0)
     1        ReadOn=.False.
      End Do

      Int = 0

      Do While (Int .LT. (Zbndi - 1))
         Read (XFile, 200) Int, (Flux(J), J = 9, 16)
      End Do

      I = 2
      Do While (I .LE. (N - 1))
         Read (XFile, 200) Int, (Flux(J), J = 9, 16)
         Do J = 9, 16
            Dose(I) = Dose(I) + 1.602E-10 * (E18(J) + E18(J+1))
     1                  / 2.0 * mu(J) * Flux(J)
         End Do
         I = I + 1
      End Do


C       Read Flux for Groups 17 and 18

  300   Format (1X, I4, 8(1X, E12.5))

      ReadOn=.True.
      Do While (ReadOn)
         Read (XFile, 100) Line$
         If (Index(Line$, 'GRP. 17') .GT. 0)
     1        ReadOn=.False.
      End Do
```

```
      Int = 0

      Do While (Int .LT. (Zbndi - 1))
         Read (XFile, 300) Int, Flux(17), Flux(18)
      End Do

      I = 2
      Do While (I .LE. (N - 1))
         Read (XFile, 300) Int, Flux(17), Flux(18)
         Do J = 17, 18
            Dose(I) = Dose(I) + 1.602E-10 * (E18(J) + E18(J+1))
     1                  / 2.0 * mu(J) * Flux(J)
         End Do
         I = I + 1
      End Do

      Return

      End

*****************************************************************
*****************************************************************


      Real Function Interp (X, X1, X2, Y1, Y2)

      Implicit None

      Real X, X1, X2, Y1, Y2

      Interp = Y1 + (X - X1) * (Y2 - Y1) / (X2 - X1)

      Return

      End

*****************************************************************
*****************************************************************


      Real Function hWater (Tw, Tinf, L)

      Implicit None

      Integer I, N

      Real Tinf, Tw, L, Tf, Ff, Prf, kf, Nuss, GrPr
      Real T(15), F(15), Pr(15), k(15), Interp

      Data T /4.44,10.0,15.56,21.11,26.67,32.22,37.78,
     1          43.33,48.89,54.44,60.0,65.55,71.11,76.67,82.22 /

      Data F /1.91E9,6.34E9,1.08E10,1.46E10,1.91E10,2.48E10,
     1          3.3E10,4.19E10,4.89E10,5.66E10,6.48E10,7.62E10,
     1          8.84E10,9.85E10,1.09E11 /

      Data Pr /11.35,9.40,7.88,6.78,5.85,5.12,4.53,4.04,
```

```
     1           3.64,3.30,3.01,2.73,2.53,2.33,2.16/

      Data k /0.575,0.585,0.595,0.604,0.614,0.623,0.630,
     1          0.637,0.644,0.649,0.654,0.659,0.665,0.668,0.673 /

      Tf = (Tinf + Tw) / 2.0

      Do I = 1, 14
         If ((Tf .GE. T(I)) .AND. (Tf .LT. T(I + 1))) N = I
      End Do

      Ff  = Interp (Tf, T(N), T(N + 1), F(N), F(N + 1))
      kf  = Interp (Tf, T(N), T(N + 1), k(N), k(N + 1))
      Prf = Interp (Tf, T(N), T(N + 1), Pr(N), Pr(N + 1))

      GrPr = Ff * (L**3.0) * Abs(Tw - Tinf)

      Nuss = (0.825 + 0.387 * Exp(1.0 / 6.0 * alog(GrPr)) /
     1             exp((8.0/27.0)*alog(1.0 + exp(9.0/16.0 *
     1             alog(0.492 / Prf)))) )**2

      hWater = kf / L * Nuss

C       Convert W/ m2 C to W/ cm2 C

      hWater = hWater * 1.0E-4

      Return
      End


*****************************************************************
*****************************************************************


      Real Function hAir (Tw, Tinf, L)

      Implicit None

      Integer I, N

      Real Tinf, Tw, L, Tf, nuf, Prf, kf, Nuss, GrPr, g
      Real T(15), nu(15), Pr(15), k(15), Interp

      Data T /100.0,150.0,200.0,250.0,300.0,350.0,400.0,450.0,
     1          500.0,550.0,600.0,650.0,700.0,750.0,800.0       /

      Data nu /1.923E-6,4.343E-6,7.490E-6,11.31E-6,15.69E-6,
     1           20.76E-6,25.90E-6,31.71E-6,37.90E-6,44.34E-6,
     1           51.34E-6,58.51E-6,66.25E-6,73.91E-6,82.29E-6 /

      Data Pr /0.770,0.753,0.739,0.722,0.708,0.697,0.689,0.683,
     1           0.680,0.680,0.680,0.682,0.684,0.686,0.689 /


      Data K /0.009246,0.013735,0.01809,0.02227,0.02624,
     1          0.03003,0.03365,0.03707,0.04038,0.04360,
     1          0.04659,0.04953,0.05230,0.05509,0.05779 /

      g = 9.81
```

```
      Tf = (Tinf + Tw) / 2.0

C       Convert to Absolute Temperature (Celcius to Kelvin)

      Tf = Tf + 273.15

      Do I = 1, 14
         If ((Tf .GE. T(I)) .AND. (Tf .LT. T(I + 1))) N = I
      End Do

      nuf = Interp (Tf, T(N), T(N + 1), nu(N), nu(N + 1))
      kf  = Interp (Tf, T(N), T(N + 1), k(N), k(N + 1))
      Prf = Interp (Tf, T(N), T(N + 1), Pr(N), Pr(N + 1))

      GrPr = g * 1.0 / Tf * Abs (Tw - Tinf) * (L**3.0) /
     1      (nuf**2.0) * Prf

      Nuss = (0.825 + 0.387 * Exp(1.0 / 6.0 * alog(GrPr)) /
     1             exp((8.0/27.0)*alog(1.0 + exp(9.0/16.0 *
     1             alog(0.492 / Prf)))) )**2

      hAir = kf / L * Nuss

C       Convert W/ m2 C to W/ cm2 C

      hAir = hAir * 1.0E-4

      Return
      End


*****************************************************************
*****************************************************************
```

Appendix B: DKPOWR Data

Description of 19 Group to 18 Group Conversion of DKPOWR ANS Source Spectrum

The 22 decay period detailed source calculations provided by INEL had to be modified in two respects before they would be ready for use as a source spectrum in the SCALE system. The first modification was to collapse the 19 energy group spectrum provided by INEL to an 18 energy group spectrum that would match that used by the SCALE system. The algorithm used for this conversion is given in Figure B1 . The algorithm constructed used an assumption of a linear (or proportional) distribution of flux across a given energy group. This assumption was deemed appropriate because of its simplicity, conservation of total flux, and lack of information indicating a more valid type of distribution.

The other assumption necessary for making the conversion from the DKPOWR gamma decay power values (MeV/s) to an eighteen group gamma emission rate was to assume the average energy for each group is the group midpoint. Then dividing the decay power by the group midpoint yields the gamma emissions. This average energy assumption can be justified by the fact that the particles within an energy group should be evenly distributed in energy, so the midpoint energy should be close to the average energy.

Our energies		
ours1	10.00	8.00
ours2	8.00	6.50
ours3	6.50	5.00
ours4	5.00	4.00
ours5	4.00	3.00
ours6	3.00	2.50
ours7	2.50	2.00
ours8	2.00	1.66
ours9	1.66	1.33
ours10	1.33	1.00
ours11	1.00	0.80
ours12	0.80	0.60
ours13	0.60	0.40
ours14	0.40	0.30
ours15	0.30	0.20
ours16	0.20	0.10
ours17	0.10	0.05
ours18	0.05	0.01

Conversion from 19 to 18 groups
ours1= 0
ours2= 0.6777*(g1)
ours3= 0.3333*(g1)+g2
ours4= g3
ours5= g4
ours6= g5+0.5*(g6)
ours7= 0.5*(g6)+g7+g8
ours8= g9+0.7*(g10)
ours9= 0.3*(g10)+g11+0.35*(g12)
ours10= 0.65*(g12)+g13
ours11= g14
ours12= g15
ours13= g16
ours14= 0.5*(g17)
ours15= 0.5*(g17)
ours16= g18
ours17= 0.5*(g19)
ours18= 0.5*(g19)

Their energies		
g1	7.50	6.00
g2	6.00	5.00
g3	5.00	4.00
g4	4.00	3.00
g5	3.00	2.60
g6	2.60	2.40
g7	2.40	2.20
g8	2.20	2.00
g9	2.00	1.80
g10	1.80	1.60
g11	1.60	1.40
g12	1.40	1.20
g13	1.20	1.00
g14	1.00	0.80
g15	0.80	0.60
g16	0.60	0.40
g17	0.40	0.20
g18	0.20	0.10
g19	0.10	0.00

table vii- 1

fission product decay spectra at cooling time of 0.0000E+00 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 0

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	2.797E+17	0.05	5.594E+18	18	0.01	0.05	2.797E+18	1.767E+18	1.030E+18
18	0.10	0.20	9.491E+17	0.15	6.327E+18	17	0.05	0.10	2.797E+18	1.767E+18	1.030E+18
17	0.20	0.40	2.793E+18	0.30	9.310E+18	16	0.10	0.20	6.327E+18	3.996E+18	2.331E+18
16	0.40	0.60	4.884E+18	0.50	9.768E+18	15	0.20	0.30	4.655E+18	2.940E+18	1.715E+18
15	0.60	0.80	6.087E+18	0.70	8.696E+18	14	0.30	0.40	4.655E+18	2.940E+18	1.715E+18
14	0.80	1.00	6.813E+18	0.90	7.570E+18	13	0.40	0.60	9.768E+18	6.169E+18	3.599E+18
13	1.00	1.20	4.365E+18	1.10	3.968E+18	12	0.60	0.80	8.696E+18	5.492E+18	3.204E+18
12	1.20	1.40	4.831E+18	1.30	3.716E+18	11	0.80	1.00	7.570E+18	4.781E+18	2.789E+18
11	1.40	1.60	4.740E+18	1.50	3.160E+18	10	1.00	1.33	6.384E+18	4.032E+18	2.352E+18
10	1.60	1.80	2.882E+18	1.70	1.695E+18	9	1.33	1.66	4.969E+18	3.138E+18	1.831E+18
9	1.80	2.00	2.801E+18	1.90	1.474E+18	8	1.66	2.00	2.661E+18	1.681E+18	9.803E+17
8	2.00	2.20	2.405E+18	2.10	1.145E+18	7	2.00	2.50	2.544E+18	1.607E+18	9.372E+17
7	2.20	2.40	2.288E+18	2.30	9.948E+17	6	2.50	3.00	1.429E+18	9.024E+17	5.264E+17
6	2.40	2.60	2.019E+18	2.50	8.076E+17	5	3.00	4.00	1.222E+18	7.716E+17	4.501E+17
5	2.60	3.00	2.870E+18	2.80	1.025E+18	4	4.00	5.00	4.136E+17	2.612E+17	1.524E+17
4	3.00	4.00	4.276E+18	3.50	1.222E+18	3	5.00	6.50	1.018E+17	6.426E+16	3.749E+16
3	4.00	5.00	1.861E+18	4.50	4.136E+17	2	6.50	8.00	2.886E+15	1.823E+15	1.063E+15
2	5.00	6.00	5.517E+17	5.50	1.003E+17	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	2.922E+16	6.75	4.329E+15						
total	0.00	7.50	5.772E+19		6.699E+19		0.01	10.00	6.699E+19	4.231E+19	2.468E+19

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 2

fission product decay spectra at cooling time of 8.6400E+04 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 1 day

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	6.543E+16	0.05	1.309E+18	18	0.01	0.05	6.543E+17	4.132E+17	2.410E+17
18	0.10	0.20	1.099E+17	0.15	7.327E+17	17	0.05	0.10	6.543E+17	4.132E+17	2.410E+17
17	0.20	0.40	3.001E+17	0.30	1.000E+18	16	0.10	0.20	7.327E+17	4.628E+17	2.700E+17
16	0.40	0.60	6.154E+17	0.50	1.231E+18	15	0.20	0.30	5.002E+17	3.159E+17	1.843E+17
15	0.60	0.80	1.383E+18	0.70	1.975E+18	14	0.30	0.40	5.002E+17	3.159E+17	1.843E+17
14	0.80	1.00	3.454E+17	0.90	3.838E+17	13	0.40	0.60	1.231E+18	7.773E+17	4.534E+17
13	1.00	1.20	9.517E+16	1.10	8.651E+16	12	0.60	0.80	1.975E+18	1.248E+18	7.277E+17
12	1.20	1.40	1.021E+17	1.30	7.851E+16	11	0.80	1.00	3.838E+17	2.424E+17	1.414E+17
11	1.40	1.60	8.975E+17	1.50	5.983E+17	10	1.00	1.33	1.375E+17	8.687E+16	5.067E+16
10	1.60	1.80	3.139E+16	1.70	1.846E+16	9	1.33	1.66	6.313E+17	3.987E+17	2.326E+17
9	1.80	2.00	2.049E+16	1.90	1.078E+16	8	1.66	2.00	2.371E+16	1.497E+16	8.734E+15
8	2.00	2.20	1.305E+16	2.10	6.214E+15	7	2.00	2.50	2.471E+16	1.560E+16	9.102E+15
7	2.20	2.40	1.607E+16	2.30	6.988E+15	6	2.50	3.00	1.204E+16	7.604E+15	4.436E+15
6	2.40	2.60	5.753E+16	2.50	2.301E+16	5	3.00	4.00	1.528E+14	9.650E+13	5.629E+13
5	2.60	3.00	1.496E+15	2.80	5.343E+14	4	4.00	5.00	1.761E+12	1.112E+12	6.489E+11
4	3.00	4.00	5.348E+14	3.50	1.528E+14	3	5.00	6.50	9.828E+03	6.207E+03	3.621E+03
3	4.00	5.00	7.926E+12	4.50	1.761E+12	2	6.50	8.00	5.501E+02	3.475E+02	2.027E+02
2	5.00	6.00	5.254E+04	5.50	9.553E+03	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	5.570E+03	6.75	8.252E+02						
total	0.00	7.50	4.054E+18		7.461E+18		0.01	10.00	7.461E+18	4.712E+18	2.749E+18

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 3

fission product decay spectra at cooling time of 1.7280E+05 seconds time= 2 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	5.71E+16	0.05	1.143E+18	18	0.01	0.05	5.715E+17	3.609E+17	2.105E+17
18	0.10	0.20	8.97E+16	0.15	5.981E+17	17	0.05	0.10	5.715E+17	3.609E+17	2.105E+17
17	0.20	0.40	2.27E+17	0.30	7.583E+17	16	0.10	0.20	5.981E+17	3.777E+17	2.203E+17
16	0.40	0.60	4.81E+17	0.50	9.620E+17	15	0.20	0.30	3.791E+17	2.395E+17	1.397E+17
15	0.60	0.80	1.06E+18	0.70	1.520E+18	14	0.30	0.40	3.791E+17	2.395E+17	1.397E+17
14	0.80	1.00	2.90E+17	0.90	3.227E+17	13	0.40	0.60	9.620E+17	6.076E+17	3.544E+17
13	1.00	1.20	3.98E+16	1.10	3.621E+16	12	0.60	0.80	1.520E+18	9.601E+17	5.601E+17
12	1.20	1.40	6.51E+16	1.30	5.005E+16	11	0.80	1.00	3.227E+17	2.038E+17	1.189E+17
11	1.40	1.60	8.74E+17	1.50	5.824E+17	10	1.00	1.33	6.874E+16	4.341E+16	2.532E+16
10	1.60	1.80	7.54E+15	1.70	4.432E+15	9	1.33	1.66	6.012E+17	3.797E+17	2.215E+17
9	1.80	2.00	9.28E+15	1.90	4.886E+15	8	1.66	2.00	7.989E+15	5.046E+15	2.943E+15
8	2.00	2.20	1.01E+16	2.10	4.813E+15	7	2.00	2.50	2.174E+16	1.373E+16	8.011E+15
7	2.20	2.40	1.38E+16	2.30	5.981E+15	6	2.50	3.00	1.136E+16	7.175E+15	4.186E+15
6	2.40	2.60	5.47E+16	2.50	2.190E+16	5	3.00	4.00	1.337E+14	8.443E+13	4.925E+13
5	2.60	3.00	1.15E+15	2.80	4.116E+14	4	4.00	5.00	5.148E+09	3.251E+09	1.896E+09
4	3.00	4.00	4.68E+14	3.50	1.337E+14	3	5.00	6.50	7.063E+03	4.461E+03	2.602E+03
3	4.00	5.00	2.32E+10	4.50	5.148E+09	2	6.50	8.00	3.830E+02	2.419E+02	1.411E+02
2	5.00	6.00	3.78E+04	5.50	6.871E+03	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	3.88E+03	6.75	5.745E+02						
total	0.00	7.50	3.29E+18		6.015E+18		0.01	10.00	6.015E+18	3.799E+18	2.216E+18

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 4

fission product decay spectra at cooling time of 2.5920E+05 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 3 days

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	4.996E+16	0.05	9.992E+17	18	0.01	0.05	4.996E+17	3.155E+17	1.841E+17
18	0.10	0.20	7.661E+16	0.15	5.107E+17	17	0.05	0.10	4.996E+17	3.155E+17	1.841E+17
17	0.20	0.40	1.874E+17	0.30	6.246E+17	16	0.10	0.20	5.107E+17	3.226E+17	1.882E+17
16	0.40	0.60	4.171E+17	0.50	8.341E+17	15	0.20	0.30	3.123E+17	1.972E+17	1.151E+17
15	0.60	0.80	9.005E+17	0.70	1.286E+18	14	0.30	0.40	3.123E+17	1.972E+17	1.151E+17
14	0.80	1.00	2.601E+17	0.90	2.890E+17	13	0.40	0.60	8.341E+17	5.268E+17	3.073E+17
13	1.00	1.20	2.489E+16	1.10	2.263E+16	12	0.60	0.80	1.286E+18	8.125E+17	4.739E+17
12	1.20	1.40	4.863E+16	1.30	3.741E+16	11	0.80	1.00	2.890E+17	1.825E+17	1.065E+17
11	1.40	1.60	8.474E+17	1.50	5.649E+17	10	1.00	1.33	4.694E+16	2.965E+16	1.729E+16
10	1.60	1.80	3.570E+15	1.70	2.100E+15	9	1.33	1.66	5.787E+17	3.655E+17	2.132E+17
9	1.80	2.00	6.702E+15	1.90	3.527E+15	8	1.66	2.00	4.997E+15	3.156E+15	1.841E+15
8	2.00	2.20	8.605E+15	2.10	4.098E+15	7	2.00	2.50	2.017E+16	1.274E+16	7.432E+15
7	2.20	2.40	1.283E+16	2.30	5.578E+15	6	2.50	3.00	1.089E+16	6.879E+15	4.013E+15
6	2.40	2.60	5.249E+16	2.50	2.100E+16	5	3.00	4.00	1.291E+14	8.154E+13	4.757E+13
5	2.60	3.00	1.105E+15	2.80	3.948E+14	4	4.00	5.00	1.878E+07	1.186E+07	6.920E+06
4	3.00	4.00	4.519E+14	3.50	1.291E+14	3	5.00	6.50	5.074E+03	3.205E+03	1.869E+03
3	4.00	5.00	8.452E+07	4.50	1.878E+07	2	6.50	8.00	2.652E+02	1.675E+02	9.771E+01
2	5.00	6.00	2.718E+04	5.50	4.941E+03	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	2.685E+03	6.75	3.978E+02						
total	0.00	7.50	2.898E+18		5.206E+18		0.01	10.00	5.206E+18	3.288E+18	1.918E+18

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 5

fission product decay spectra at cooling time of 3.4560E+05 seconds time= 4 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	4.373E+16	0.05	8.747E+17	18	0.01	0.05	4.373E+17	2.762E+17	1.611E+17
18	0.10	0.20	6.699E+16	0.15	4.466E+17	17	0.05	0.10	4.373E+17	2.762E+17	1.611E+17
17	0.20	0.40	1.604E+17	0.30	5.347E+17	16	0.10	0.20	4.466E+17	2.821E+17	1.645E+17
16	0.40	0.60	3.806E+17	0.50	7.611E+17	15	0.20	0.30	2.673E+17	1.688E+17	9.849E+16
15	0.60	0.80	7.961E+17	0.70	1.137E+18	14	0.30	0.40	2.673E+17	1.688E+17	9.849E+16
14	0.80	1.00	2.363E+17	0.90	2.625E+17	13	0.40	0.60	7.611E+17	4.807E+17	2.804E+17
13	1.00	1.20	1.840E+16	1.10	1.673E+16	12	0.60	0.80	1.137E+18	7.182E+17	4.190E+17
12	1.20	1.40	3.792E+16	1.30	2.917E+16	11	0.80	1.00	2.625E+17	1.658E+17	9.671E+16
11	1.40	1.60	8.130E+17	1.50	5.420E+17	10	1.00	1.33	3.569E+16	2.254E+16	1.315E+16
10	1.60	1.80	2.464E+15	1.70	1.449E+15	9	1.33	1.66	5.527E+17	3.490E+17	2.036E+17
9	1.80	2.00	5.318E+15	1.90	2.799E+15	8	1.66	2.00	3.813E+15	2.408E+15	1.405E+15
8	2.00	2.20	7.379E+15	2.10	3.514E+15	7	2.00	2.50	1.878E+16	1.186E+16	6.920E+15
7	2.20	2.40	1.201E+16	2.30	5.223E+15	6	2.50	3.00	1.043E+16	6.584E+15	3.841E+15
6	2.40	2.60	5.023E+16	2.50	2.009E+16	5	3.00	4.00	1.241E+14	7.837E+13	4.572E+13
5	2.60	3.00	1.060E+15	2.80	3.784E+14	4	4.00	5.00	1.031E+05	6.512E+04	3.799E+04
4	3.00	4.00	4.343E+14	3.50	1.241E+14	3	5.00	6.50	3.680E+03	2.324E+03	1.356E+03
3	4.00	5.00	4.640E+05	4.50	1.031E+05	2	6.50	8.00	1.835E+02	1.159E+02	6.759E+01
2	5.00	6.00	1.973E+04	5.50	3.588E+03	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	1.857E+03	6.75	2.752E+02						
total	0.00	7.50	2.632E+18		4.638E+18		0.01	10.00	4.638E+18	2.929E+18	1.709E+18

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 6

fission product decay spectra at cooling time of 1.8144E+06 seconds time= 21 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	9.127E+15	0.05	1.825E+17	18	0.01	0.05	9.127E+16	5.764E+16	3.363E+16
18	0.10	0.20	2.579E+16	0.15	1.719E+17	17	0.05	0.10	9.127E+16	5.764E+16	3.363E+16
17	0.20	0.40	3.447E+16	0.30	1.149E+17	16	0.10	0.20	1.719E+17	1.086E+17	6.334E+16
16	0.40	0.60	1.702E+17	0.50	3.403E+17	15	0.20	0.30	5.745E+16	3.629E+16	2.117E+16
15	0.60	0.80	4.381E+17	0.70	6.258E+17	14	0.30	0.40	5.745E+16	3.629E+16	2.117E+16
14	0.80	1.00	7.690E+16	0.90	8.545E+16	13	0.40	0.60	3.403E+17	2.149E+17	1.254E+17
13	1.00	1.20	1.536E+15	1.10	1.396E+15	12	0.60	0.80	6.258E+17	3.953E+17	2.306E+17
12	1.20	1.40	2.165E+15	1.30	1.666E+15	11	0.80	1.00	8.545E+16	5.397E+16	3.148E+16
11	1.40	1.60	3.285E+17	1.50	2.190E+17	10	1.00	1.33	2.479E+15	1.565E+15	9.132E+14
10	1.60	1.80	6.907E+13	1.70	4.063E+13	9	1.33	1.66	2.196E+17	1.387E+17	8.090E+16
9	1.80	2.00	4.509E+14	1.90	2.373E+14	8	1.66	2.00	2.658E+14	1.679E+14	9.791E+13
8	2.00	2.20	1.702E+15	2.10	8.105E+14	7	2.00	2.50	6.948E+15	4.388E+15	2.560E+15
7	2.20	2.40	4.465E+15	2.30	1.941E+15	6	2.50	3.00	4.347E+15	2.746E+15	1.602E+15
6	2.40	2.60	2.098E+16	2.50	8.393E+15	5	3.00	4.00	5.121E+13	3.234E+13	1.887E+13
5	2.60	3.00	4.229E+14	2.80	1.510E+14	4	4.00	5.00	6.321E+01	3.992E+01	2.329E+01
4	3.00	4.00	1.792E+14	3.50	5.121E+13	3	5.00	6.50	2.726E+02	1.721E+02	1.004E+02
3	4.00	5.00	2.844E+02	4.50	6.321E+01	2	6.50	8.00	3.397E-01	2.146E-01	1.252E-01
2	5.00	6.00	1.498E+03	5.50	2.724E+02	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	3.440E+00	6.75	5.096E-01						
total	0.00	7.50	1.115E+18		1.755E+18		0.01	10.00	1.755E+18	1.108E+18	6.464E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 7

fission product decay spectra at cooling time of 3.6288E+06 seconds time= 42 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	3.221E+15	0.05	6.443E+16	18	0.01	0.05	3.221E+16	2.035E+16	1.187E+16
18	0.10	0.20	1.600E+16	0.15	1.066E+17	17	0.05	0.10	3.221E+16	2.035E+16	1.187E+16
17	0.20	0.40	8.532E+15	0.30	2.844E+16	16	0.10	0.20	1.066E+17	6.735E+16	3.929E+16
16	0.40	0.60	7.900E+16	0.50	1.580E+17	15	0.20	0.30	1.422E+16	8.981E+15	5.239E+15
15	0.60	0.80	3.777E+17	0.70	5.396E+17	14	0.30	0.40	1.422E+16	8.981E+15	5.239E+15
14	0.80	1.00	2.334E+16	0.90	2.593E+16	13	0.40	0.60	1.580E+17	9.978E+16	5.821E+16
13	1.00	1.20	4.769E+14	1.10	4.336E+14	12	0.60	0.80	5.396E+17	3.408E+17	1.988E+17
12	1.20	1.40	8.791E+14	1.30	6.762E+14	11	0.80	1.00	2.593E+16	1.638E+16	9.554E+15
11	1.40	1.60	1.081E+17	1.50	7.205E+16	10	1.00	1.33	8.731E+14	5.514E+14	3.217E+14
10	1.60	1.80	1.003E+13	1.70	5.897E+12	9	1.33	1.66	7.229E+16	4.565E+16	2.663E+16
9	1.80	2.00	1.354E+14	1.90	7.127E+13	8	1.66	2.00	7.540E+13	4.762E+13	2.778E+13
8	2.00	2.20	1.381E+15	2.10	6.578E+14	7	2.00	2.50	2.603E+15	1.644E+15	9.590E+14
7	2.20	2.40	1.415E+15	2.30	6.153E+14	6	2.50	3.00	1.376E+15	8.692E+14	5.070E+14
6	2.40	2.60	6.649E+15	2.50	2.660E+15	5	3.00	4.00	1.629E+13	1.029E+13	6.003E+12
5	2.60	3.00	1.300E+14	2.80	4.643E+13	4	4.00	5.00	3.448E-02	2.178E-02	1.270E-02
4	3.00	4.00	5.703E+13	3.50	1.629E+13	3	5.00	6.50	4.419E+01	2.791E+01	1.628E+01
3	4.00	5.00	1.552E-01	4.50	3.448E-02	2	6.50	8.00	1.436E-04	9.072E-05	5.292E-05
2	5.00	6.00	2.431E+02	5.50	4.419E+01	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	1.454E-03	6.75	2.155E-04						
total	0.00	7.50	6.270E+17		1.000E+18		0.01	10.00	1.000E+18	6.317E+17	3.685E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 8

fission product decay spectra at cooling time of 5.4432E+06 seconds time= 63 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.783E+15	0.05	3.566E+16	18	0.01	0.05	1.783E+16	1.126E+16	6.570E+15
18	0.10	0.20	1.024E+16	0.15	6.827E+16	17	0.05	0.10	1.783E+16	1.126E+16	6.570E+15
17	0.20	0.40	2.467E+15	0.30	8.222E+15	16	0.10	0.20	6.827E+16	4.312E+16	2.515E+16
16	0.40	0.60	4.391E+16	0.50	8.782E+16	15	0.20	0.30	4.111E+15	2.596E+15	1.515E+15
15	0.60	0.80	3.238E+17	0.70	4.626E+17	14	0.30	0.40	4.111E+15	2.596E+15	1.515E+15
14	0.80	1.00	7.463E+15	0.90	8.292E+15	13	0.40	0.60	8.782E+16	5.546E+16	3.235E+16
13	1.00	1.20	2.453E+14	1.10	2.230E+14	12	0.60	0.80	4.626E+17	2.922E+17	1.704E+17
12	1.20	1.40	6.530E+14	1.30	5.023E+14	11	0.80	1.00	8.292E+15	5.237E+15	3.055E+15
11	1.40	1.60	3.507E+16	1.50	2.338E+16	10	1.00	1.33	5.495E+14	3.470E+14	2.024E+14
10	1.60	1.80	8.154E+12	1.70	4.797E+12	9	1.33	1.66	2.356E+16	1.488E+16	8.678E+15
9	1.80	2.00	4.914E+13	1.90	2.586E+13	8	1.66	2.00	2.922E+13	1.845E+13	1.076E+13
8	2.00	2.20	1.298E+15	2.10	6.182E+14	7	2.00	2.50	1.237E+15	7.816E+14	4.559E+14
7	2.20	2.40	4.545E+14	2.30	1.976E+14	6	2.50	3.00	4.369E+14	2.760E+14	1.610E+14
6	2.40	2.60	2.108E+15	2.50	8.433E+14	5	3.00	4.00	5.269E+12	3.328E+12	1.941E+12
5	2.60	3.00	4.277E+13	2.80	1.527E+13	4	4.00	5.00	1.881E-05	1.188E-05	6.930E-06
4	3.00	4.00	1.844E+13	3.50	5.269E+12	3	5.00	6.50	7.201E+00	4.548E+00	2.653E+00
3	4.00	5.00	8.464E-05	4.50	1.881E-05	2	6.50	8.00	6.146E-08	3.882E-08	2.264E-08
2	5.00	6.00	3.961E+01	5.50	7.201E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	6.223E-07	6.75	9.219E-08						
total	0.00	7.50	4.296E+17		6.967E+17		0.01	10.00	6.967E+17	4.400E+17	2.567E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 9

fission product decay spectra at cooling time of 7.2576E+06 seconds time= 84 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.160E+15	0.05	2.320E+16	18	0.01	0.05	1.160E+16	7.325E+15	4.273E+15
18	0.10	0.20	6.704E+15	0.15	4.470E+16	17	0.05	0.10	1.160E+16	7.325E+15	4.273E+15
17	0.20	0.40	8.038E+14	0.30	2.679E+15	16	0.10	0.20	4.470E+16	2.823E+16	1.647E+16
16	0.40	0.60	2.736E+16	0.50	5.472E+16	15	0.20	0.30	1.340E+15	8.461E+14	4.936E+14
15	0.60	0.80	2.744E+17	0.70	3.920E+17	14	0.30	0.40	1.340E+15	8.461E+14	4.936E+14
14	0.80	1.00	2.492E+15	0.90	2.769E+15	13	0.40	0.60	5.472E+16	3.456E+16	2.016E+16
13	1.00	1.20	1.699E+14	1.10	1.544E+14	12	0.60	0.80	3.920E+17	2.476E+17	1.444E+17
12	1.20	1.40	5.033E+14	1.30	3.871E+14	11	0.80	1.00	2.769E+15	1.749E+15	1.020E+15
11	1.40	1.60	1.121E+16	1.50	7.474E+15	10	1.00	1.33	4.061E+14	2.565E+14	1.496E+14
10	1.60	1.80	7.532E+12	1.70	4.430E+12	9	1.33	1.66	7.611E+15	4.807E+15	2.804E+15
9	1.80	2.00	1.948E+13	1.90	1.025E+13	8	1.66	2.00	1.335E+13	8.433E+12	4.919E+12
8	2.00	2.20	1.229E+15	2.10	5.850E+14	7	2.00	2.50	7.843E+14	4.953E+14	2.890E+14
7	2.20	2.40	1.491E+14	2.30	6.483E+13	6	2.50	3.00	1.399E+14	8.835E+13	5.154E+13
6	2.40	2.60	6.723E+14	2.50	2.689E+14	5	3.00	4.00	1.774E+12	1.120E+12	6.536E+11
5	2.60	3.00	1.519E+13	2.80	5.423E+12	4	4.00	5.00	1.026E-08	6.481E-09	3.781E-09
4	3.00	4.00	6.209E+12	3.50	1.774E+12	3	5.00	6.50	1.173E+00	7.410E-01	4.323E-01
3	4.00	5.00	4.618E-08	4.50	1.026E-08	2	6.50	8.00	2.650E-11	1.674E-11	9.765E-12
2	5.00	6.00	6.453E+00	5.50	1.173E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	2.683E-10	6.75	3.975E-11						
total	0.00	7.50	3.269E+17		5.290E+17		0.01	10.00	5.290E+17	3.341E+17	1.949E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-10

fission product decay spectra at cooling time of 1.0886E+07 seconds time= 126 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	6.382E+14	0.05	1.276E+16	18	0.01	0.05	6.382E+15	4.031E+15	2.351E+15
18	0.10	0.20	3.166E+15	0.15	2.111E+16	17	0.05	0.10	6.382E+15	4.031E+15	2.351E+15
17	0.20	0.40	1.400E+14	0.30	4.665E+14	16	0.10	0.20	2.111E+16	1.333E+16	7.776E+15
16	0.40	0.60	1.231E+16	0.50	2.461E+16	15	0.20	0.30	2.333E+14	1.473E+14	8.593E+13
15	0.60	0.80	1.921E+17	0.70	2.744E+17	14	0.30	0.40	2.333E+14	1.473E+14	8.593E+13
14	0.80	1.00	3.161E+14	0.90	3.513E+14	13	0.40	0.60	2.461E+16	1.555E+16	9.068E+15
13	1.00	1.20	1.238E+14	1.10	1.126E+14	12	0.60	0.80	2.744E+17	1.733E+17	1.011E+17
12	1.20	1.40	3.028E+14	1.30	2.329E+14	11	0.80	1.00	3.513E+14	2.219E+14	1.294E+14
11	1.40	1.60	1.313E+15	1.50	8.753E+14	10	1.00	1.33	2.640E+14	1.667E+14	9.725E+13
10	1.60	1.80	6.744E+12	1.70	3.967E+12	9	1.33	1.66	9.580E+14	6.051E+14	3.530E+14
9	1.80	2.00	5.531E+12	1.90	2.911E+12	8	1.66	2.00	5.688E+12	3.592E+12	2.095E+12
8	2.00	2.20	1.105E+15	2.10	5.263E+14	7	2.00	2.50	5.493E+14	3.469E+14	2.024E+14
7	2.20	2.40	2.033E+13	2.30	8.839E+12	6	2.50	3.00	1.535E+13	9.694E+12	5.655E+12
6	2.40	2.60	7.090E+13	2.50	2.836E+13	5	3.00	4.00	2.930E+11	1.850E+11	1.079E+11
5	2.60	3.00	3.272E+12	2.80	1.169E+12	4	4.00	5.00	3.055E-15	1.930E-15	1.126E-15
4	3.00	4.00	1.025E+12	3.50	2.930E+11	3	5.00	6.50	3.115E-02	1.967E-02	1.148E-02
3	4.00	5.00	1.375E-14	4.50	3.055E-15	2	6.50	8.00	4.995E-18	3.155E-18	1.840E-18
2	5.00	6.00	1.713E-01	5.50	3.115E-02	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	5.058E-17	6.75	7.493E-18						
total	0.00	7.50	2.116E+17		3.355E+17		0.01	10.00	3.355E+17	2.119E+17	1.236E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-11

fission product decay spectra at cooling time of 1.5552E+07 seconds time= 180 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	4.265E+14	0.05	8.531E+15	18	0.01	0.05	4.265E+15	2.694E+15	1.571E+15
18	0.10	0.20	1.562E+15	0.15	1.041E+16	17	0.05	0.10	4.265E+15	2.694E+15	1.571E+15
17	0.20	0.40	4.596E+13	0.30	1.532E+14	16	0.10	0.20	1.041E+16	6.576E+15	3.836E+15
16	0.40	0.60	4.887E+15	0.50	9.773E+15	15	0.20	0.30	7.660E+13	4.838E+13	2.822E+13
15	0.60	0.80	1.176E+17	0.70	1.681E+17	14	0.30	0.40	7.660E+13	4.838E+13	2.822E+13
14	0.80	1.00	4.088E+13	0.90	4.542E+13	13	0.40	0.60	9.773E+15	6.173E+15	3.601E+15
13	1.00	1.20	1.046E+14	1.10	9.512E+13	12	0.60	0.80	1.681E+17	1.061E+17	6.192E+16
12	1.20	1.40	1.592E+14	1.30	1.225E+14	11	0.80	1.00	4.542E+13	2.869E+13	1.673E+13
11	1.40	1.60	3.247E+14	1.50	2.165E+14	10	1.00	1.33	1.747E+14	1.104E+14	6.438E+13
10	1.60	1.80	5.997E+12	1.70	3.528E+12	9	1.33	1.66	2.604E+14	1.645E+14	9.594E+13
9	1.80	2.00	3.455E+12	1.90	1.818E+12	8	1.66	2.00	4.288E+12	2.708E+12	1.580E+12
8	2.00	2.20	9.676E+14	2.10	4.608E+14	7	2.00	2.50	4.645E+14	2.934E+14	1.711E+14
7	2.20	2.40	5.803E+12	2.30	2.523E+12	6	2.50	3.00	1.877E+12	1.185E+12	6.914E+11
6	2.40	2.60	6.215E+12	2.50	2.486E+12	5	3.00	4.00	1.164E+11	7.353E+10	4.289E+10
5	2.60	3.00	1.775E+12	2.80	6.339E+11	4	4.00	5.00	1.243E-23	7.848E-24	4.578E-24
4	3.00	4.00	4.075E+11	3.50	1.164E+11	3	5.00	6.50	2.932E-04	1.852E-04	1.080E-04
3	4.00	5.00	5.592E-23	4.50	1.243E-23	2	6.50	8.00	1.194E-26	7.544E-27	4.401E-27
2	5.00	6.00	1.613E-03	5.50	2.932E-04	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	1.209E-25	6.75	1.792E-26						
total	0.00	7.50	1.262E+17		1.979E+17		0.01	10.00	1.979E+17	1.250E+17	7.290E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-12

fission product decay spectra at cooling time of 2.0736E+07 seconds time= 240 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	3.381E+14	0.05	6.761E+15	18	0.01	0.05	3.381E+15	2.135E+15	1.245E+15
18	0.10	0.20	9.889E+14	0.15	6.593E+15	17	0.05	0.10	3.381E+15	2.135E+15	1.245E+15
17	0.20	0.40	2.296E+13	0.30	7.653E+13	16	0.10	0.20	6.593E+15	4.164E+15	2.429E+15
16	0.40	0.60	1.959E+15	0.50	3.917E+15	15	0.20	0.30	3.827E+13	2.417E+13	1.410E+13
15	0.60	0.80	6.674E+16	0.70	9.534E+16	14	0.30	0.40	3.827E+13	2.417E+13	1.410E+13
14	0.80	1.00	1.915E+13	0.90	2.128E+13	13	0.40	0.60	3.917E+15	2.474E+15	1.443E+15
13	1.00	1.20	9.223E+13	1.10	8.384E+13	12	0.60	0.80	9.534E+16	6.022E+16	3.513E+16
12	1.20	1.40	7.926E+13	1.30	6.097E+13	11	0.80	1.00	2.128E+13	1.344E+13	7.839E+12
11	1.40	1.60	2.441E+14	1.50	1.628E+14	10	1.00	1.33	1.235E+14	7.798E+13	4.549E+13
10	1.60	1.80	5.321E+12	1.70	3.130E+12	9	1.33	1.66	1.850E+14	1.169E+14	6.817E+13
9	1.80	2.00	2.982E+12	1.90	1.570E+12	8	1.66	2.00	3.761E+12	2.375E+12	1.386E+12
8	2.00	2.20	8.356E+14	2.10	3.979E+14	7	2.00	2.50	4.003E+14	2.529E+14	1.475E+14
7	2.20	2.40	4.458E+12	2.30	1.938E+12	6	2.50	3.00	1.030E+12	6.507E+11	3.796E+11
6	2.40	2.60	2.452E+12	2.50	9.806E+11	5	3.00	4.00	9.442E+10	5.963E+10	3.479E+10
5	2.60	3.00	1.512E+12	2.80	5.400E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	3.305E+11	3.50	9.442E+10	3	5.00	6.50	1.644E-06	1.038E-06	6.056E-07
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	9.040E-06	5.50	1.644E-06	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	7.134E+16		1.134E+17		0.01	10.00	1.134E+17	7.164E+16	4.179E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-13

fission product decay spectra at cooling time of 2.5920E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 300 days

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	2.853E+14	0.05	5.705E+15	18	0.01	0.05	2.853E+15	1.802E+15	1.051E+15
18	0.10	0.20	7.621E+14	0.15	5.081E+15	17	0.05	0.10	2.853E+15	1.802E+15	1.051E+15
17	0.20	0.40	1.248E+13	0.30	4.159E+13	16	0.10	0.20	5.081E+15	3.209E+15	1.872E+15
16	0.40	0.60	9.459E+14	0.50	1.892E+15	15	0.20	0.30	2.080E+13	1.313E+13	7.662E+12
15	0.60	0.80	3.762E+16	0.70	5.374E+16	14	0.30	0.40	2.080E+13	1.313E+13	7.662E+12
14	0.80	1.00	1.605E+13	0.90	1.783E+13	13	0.40	0.60	1.892E+15	1.195E+15	6.969E+14
13	1.00	1.20	8.221E+13	1.10	7.474E+13	12	0.60	0.80	5.374E+16	3.394E+16	1.980E+16
12	1.20	1.40	4.053E+13	1.30	3.118E+13	11	0.80	1.00	1.783E+13	1.126E+13	6.571E+12
11	1.40	1.60	2.089E+14	1.50	1.392E+14	10	1.00	1.33	9.501E+13	6.000E+13	3.500E+13
10	1.60	1.80	4.741E+12	1.70	2.789E+12	9	1.33	1.66	1.510E+14	9.536E+13	5.563E+13
9	1.80	2.00	2.656E+12	1.90	1.398E+12	8	1.66	2.00	3.350E+12	2.116E+12	1.234E+12
8	2.00	2.20	7.218E+14	2.10	3.437E+14	7	2.00	2.50	3.459E+14	2.184E+14	1.274E+14
7	2.20	2.40	3.946E+12	2.30	1.716E+12	6	2.50	3.00	8.919E+11	5.633E+11	3.286E+11
6	2.40	2.60	2.065E+12	2.50	8.259E+11	5	3.00	4.00	8.373E+10	5.288E+10	3.085E+10
5	2.60	3.00	1.341E+12	2.80	4.789E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	2.931E+11	3.50	8.373E+10	3	5.00	6.50	9.213E-09	5.819E-09	3.394E-09
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	5.067E-08	5.50	9.213E-09	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	4.071E+16		6.708E+16		0.01	10.00	6.708E+16	4.236E+16	2.471E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-14

fission product decay spectra at cooling time of 3.1536E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 1 year

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	2.412E+14	0.05	4.824E+15	18	0.01	0.05	2.412E+15	1.523E+15	8.886E+14
18	0.10	0.20	6.236E+14	0.15	4.157E+15	17	0.05	0.10	2.412E+15	1.523E+15	8.886E+14
17	0.20	0.40	6.761E+12	0.30	2.254E+13	16	0.10	0.20	4.157E+15	2.626E+15	1.532E+15
16	0.40	0.60	5.574E+14	0.50	1.115E+15	15	0.20	0.30	1.127E+13	7.117E+12	4.152E+12
15	0.60	0.80	2.044E+16	0.70	2.920E+16	14	0.30	0.40	1.127E+13	7.117E+12	4.152E+12
14	0.80	1.00	1.405E+13	0.90	1.561E+13	13	0.40	0.60	1.115E+15	7.041E+14	4.107E+14
13	1.00	1.20	7.274E+13	1.10	6.613E+13	12	0.60	0.80	2.920E+16	1.844E+16	1.076E+16
12	1.20	1.40	2.056E+13	1.30	1.582E+13	11	0.80	1.00	1.561E+13	9.858E+12	5.750E+12
11	1.40	1.60	1.774E+14	1.50	1.182E+14	10	1.00	1.33	7.641E+13	4.826E+13	2.815E+13
10	1.60	1.80	4.192E+12	1.70	2.466E+12	9	1.33	1.66	1.245E+14	7.865E+13	4.588E+13
9	1.80	2.00	2.347E+12	1.90	1.235E+12	8	1.66	2.00	2.961E+12	1.870E+12	1.091E+12
8	2.00	2.20	6.160E+14	2.10	2.934E+14	7	2.00	2.50	2.952E+14	1.865E+14	1.088E+14
7	2.20	2.40	3.490E+12	2.30	1.517E+12	6	2.50	3.00	7.851E+11	4.959E+11	2.893E+11
6	2.40	2.60	1.818E+12	2.50	7.273E+11	5	3.00	4.00	7.403E+10	4.675E+10	2.727E+10
5	2.60	3.00	1.180E+12	2.80	4.215E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	2.591E+11	3.50	7.403E+10	3	5.00	6.50	3.353E-11	2.118E-11	1.235E-11
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	1.844E-10	5.50	3.353E-11	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	2.278E+16		3.983E+16		0.01	10.00	3.983E+16	2.516E+16	1.467E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-15

fission product decay spectra at cooling time of 4.7304E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 1.5 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.536E+14	0.05	3.071E+15	18	0.01	0.05	1.536E+15	9.699E+14	5.657E+14
18	0.10	0.20	3.869E+14	0.15	2.579E+15	17	0.05	0.10	1.536E+15	9.699E+14	5.657E+14
17	0.20	0.40	1.878E+12	0.30	6.259E+12	16	0.10	0.20	2.579E+15	1.629E+15	9.502E+14
16	0.40	0.60	2.948E+14	0.50	5.895E+14	15	0.20	0.30	3.130E+12	1.977E+12	1.153E+12
15	0.60	0.80	4.811E+15	0.70	6.873E+15	14	0.30	0.40	3.130E+12	1.977E+12	1.153E+12
14	0.80	1.00	9.794E+12	0.90	1.088E+13	13	0.40	0.60	5.895E+14	3.723E+14	2.172E+14
13	1.00	1.20	5.164E+13	1.10	4.694E+13	12	0.60	0.80	6.873E+15	4.341E+15	2.532E+15
12	1.20	1.40	4.751E+12	1.30	3.655E+12	11	0.80	1.00	1.088E+13	6.873E+12	4.009E+12
11	1.40	1.60	1.126E+14	1.50	7.507E+13	10	1.00	1.33	4.932E+13	3.115E+13	1.817E+13
10	1.60	1.80	2.972E+12	1.70	1.748E+12	9	1.33	1.66	7.687E+13	4.855E+13	2.832E+13
9	1.80	2.00	1.659E+12	1.90	8.729E+11	8	1.66	2.00	2.097E+12	1.324E+12	7.725E+11
8	2.00	2.20	3.948E+14	2.10	1.880E+14	7	2.00	2.50	1.893E+14	1.196E+14	6.975E+13
7	2.20	2.40	2.477E+12	2.30	1.077E+12	6	2.50	3.00	5.518E+11	3.485E+11	2.033E+11
6	2.40	2.60	1.285E+12	2.50	5.142E+11	5	3.00	4.00	5.250E+10	3.316E+10	1.934E+10
5	2.60	3.00	8.252E+11	2.80	2.947E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	1.838E+11	3.50	5.250E+10	3	5.00	6.50	4.759E-18	3.005E-18	1.753E-18
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	2.617E-17	5.50	4.759E-18	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	6.231E+15		1.345E+16		0.01	10.00	1.345E+16	8.493E+15	4.955E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-16

fission product decay spectra at cooling time of 6.3072E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 2 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	9.974E+13	0.05	1.995E+15	18	0.01	0.05	9.974E+14	6.299E+14	3.675E+14
18	0.10	0.20	2.438E+14	0.15	1.626E+15	17	0.05	0.10	9.974E+14	6.299E+14	3.675E+14
17	0.20	0.40	1.083E+12	0.30	3.609E+12	16	0.10	0.20	1.626E+15	1.027E+15	5.989E+14
16	0.40	0.60	2.056E+14	0.50	4.111E+14	15	0.20	0.30	1.805E+12	1.140E+12	6.649E+11
15	0.60	0.80	2.352E+15	0.70	3.360E+15	14	0.30	0.40	1.805E+12	1.140E+12	6.649E+11
14	0.80	1.00	6.857E+12	0.90	7.619E+12	13	0.40	0.60	4.111E+14	2.597E+14	1.515E+14
13	1.00	1.20	3.666E+13	1.10	3.333E+13	12	0.60	0.80	3.360E+15	2.122E+15	1.238E+15
12	1.20	1.40	2.120E+12	1.30	1.630E+12	11	0.80	1.00	7.619E+12	4.812E+12	2.807E+12
11	1.40	1.60	7.187E+13	1.50	4.792E+13	10	1.00	1.33	3.439E+13	2.172E+13	1.267E+13
10	1.60	1.80	2.109E+12	1.70	1.241E+12	9	1.33	1.66	4.886E+13	3.086E+13	1.800E+13
9	1.80	2.00	1.172E+12	1.90	6.168E+11	8	1.66	2.00	1.485E+12	9.380E+11	5.472E+11
8	2.00	2.20	2.530E+14	2.10	1.205E+14	7	2.00	2.50	1.214E+14	7.669E+13	4.474E+13
7	2.20	2.40	1.758E+12	2.30	7.641E+11	6	2.50	3.00	3.885E+11	2.454E+11	1.431E+11
6	2.40	2.60	9.109E+11	2.50	3.644E+11	5	3.00	4.00	3.725E+10	2.353E+10	1.372E+10
5	2.60	3.00	5.777E+11	2.80	2.063E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	1.304E+11	3.50	3.725E+10	3	5.00	6.50	6.721E-25	4.245E-25	2.476E-25
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	3.697E-24	5.50	6.721E-25	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	3.279E+15		7.609E+15		0.01	10.00	7.609E+15	4.806E+15	2.803E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-17

fission product decay spectra at cooling time of 7.8840E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 2.5 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	6.644E+13	0.05	1.329E+15	18	0.01	0.05	6.644E+14	4.196E+14	2.448E+14
18	0.10	0.20	1.545E+14	0.15	1.030E+15	17	0.05	0.10	6.644E+14	4.196E+14	2.448E+14
17	0.20	0.40	8.637E+11	0.30	2.879E+12	16	0.10	0.20	1.030E+15	6.507E+14	3.795E+14
16	0.40	0.60	1.470E+14	0.50	2.939E+14	15	0.20	0.30	1.439E+12	9.091E+11	5.303E+11
15	0.60	0.80	1.912E+15	0.70	2.731E+15	14	0.30	0.40	1.439E+12	9.091E+11	5.303E+11
14	0.80	1.00	4.816E+12	0.90	5.351E+12	13	0.40	0.60	2.939E+14	1.856E+14	1.083E+14
13	1.00	1.20	2.604E+13	1.10	2.367E+13	12	0.60	0.80	2.731E+15	1.725E+15	1.006E+15
12	1.20	1.40	1.254E+12	1.30	9.644E+11	11	0.80	1.00	5.351E+12	3.380E+12	1.972E+12
11	1.40	1.60	4.611E+13	1.50	3.074E+13	10	1.00	1.33	2.430E+13	1.535E+13	8.951E+12
10	1.60	1.80	1.496E+12	1.70	8.802E+11	9	1.33	1.66	3.134E+13	1.979E+13	1.155E+13
9	1.80	2.00	8.283E+11	1.90	4.359E+11	8	1.66	2.00	1.052E+12	6.645E+11	3.876E+11
8	2.00	2.20	1.622E+14	2.10	7.721E+13	7	2.00	2.50	7.789E+13	4.919E+13	2.869E+13
7	2.20	2.40	1.247E+12	2.30	5.423E+11	6	2.50	3.00	2.738E+11	1.729E+11	1.009E+11
6	2.40	2.60	6.461E+11	2.50	2.584E+11	5	3.00	4.00	2.643E+10	1.670E+10	9.739E+09
5	2.60	3.00	4.049E+11	2.80	1.446E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	9.252E+10	3.50	2.643E+10	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	2.526E+15		5.527E+15		0.01	10.00	5.527E+15	3.491E+15	2.036E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-18

fission product decay spectra at cooling time of 9.4608E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 3 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	4.569E+13	0.05	9.137E+14	18	0.01	0.05	4.569E+14	2.885E+14	1.683E+14
18	0.10	0.20	9.855E+13	0.15	6.570E+14	17	0.05	0.10	4.569E+14	2.885E+14	1.683E+14
17	0.20	0.40	7.390E+11	0.30	2.463E+12	16	0.10	0.20	6.570E+14	4.149E+14	2.420E+14
16	0.40	0.60	1.062E+14	0.50	2.123E+14	15	0.20	0.30	1.232E+12	7.779E+11	4.538E+11
15	0.60	0.80	1.791E+15	0.70	2.559E+15	14	0.30	0.40	1.232E+12	7.779E+11	4.538E+11
14	0.80	1.00	3.392E+12	0.90	3.769E+12	13	0.40	0.60	2.123E+14	1.341E+14	7.822E+13
13	1.00	1.20	1.849E+13	1.10	1.681E+13	12	0.60	0.80	2.559E+15	1.616E+15	9.426E+14
12	1.20	1.40	7.964E+11	1.30	6.126E+11	11	0.80	1.00	3.769E+12	2.380E+12	1.388E+12
11	1.40	1.60	2.971E+13	1.50	1.981E+13	10	1.00	1.33	1.721E+13	1.087E+13	6.340E+12
10	1.60	1.80	1.062E+12	1.70	6.245E+11	9	1.33	1.66	2.021E+13	1.276E+13	7.446E+12
9	1.80	2.00	5.853E+11	1.90	3.081E+11	8	1.66	2.00	7.452E+11	4.707E+11	2.746E+11
8	2.00	2.20	1.039E+14	2.10	4.949E+13	7	2.00	2.50	4.996E+13	3.156E+13	1.841E+13
7	2.20	2.40	8.851E+11	2.30	3.848E+11	6	2.50	3.00	1.931E+11	1.220E+11	7.116E+10
6	2.40	2.60	4.584E+11	2.50	1.834E+11	5	3.00	4.00	1.876E+10	1.185E+10	6.912E+09
5	2.60	3.00	2.841E+11	2.80	1.015E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	6.566E+10	3.50	1.876E+10	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	2.202E+15		4.436E+15		0.01	10.00	4.436E+15	2.802E+15	1.634E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-19

fission product decay spectra at cooling time of 1.1038E+08 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 3.5 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	3.264E+13	0.05	6.528E+14	18	0.01	0.05	3.264E+14	2.062E+14	1.203E+14
18	0.10	0.20	6.332E+13	0.15	4.221E+14	17	0.05	0.10	3.264E+14	2.062E+14	1.203E+14
17	0.20	0.40	6.405E+11	0.30	2.135E+12	16	0.10	0.20	4.221E+14	2.666E+14	1.555E+14
16	0.40	0.60	7.748E+13	0.50	1.550E+14	15	0.20	0.30	1.068E+12	6.742E+11	3.933E+11
15	0.60	0.80	1.730E+15	0.70	2.472E+15	14	0.30	0.40	1.068E+12	6.742E+11	3.933E+11
14	0.80	1.00	2.394E+12	0.90	2.660E+12	13	0.40	0.60	1.550E+14	9.787E+13	5.709E+13
13	1.00	1.20	1.314E+13	1.10	1.194E+13	12	0.60	0.80	2.472E+15	1.561E+15	9.107E+14
12	1.20	1.40	5.176E+11	1.30	3.982E+11	11	0.80	1.00	2.660E+12	1.680E+12	9.802E+11
11	1.40	1.60	1.922E+13	1.50	1.281E+13	10	1.00	1.33	1.220E+13	7.705E+12	4.495E+12
10	1.60	1.80	7.533E+11	1.70	4.431E+11	9	1.33	1.66	1.309E+13	8.265E+12	4.822E+12
9	1.80	2.00	4.137E+11	1.90	2.177E+11	8	1.66	2.00	5.279E+11	3.334E+11	1.945E+11
8	2.00	2.20	6.660E+13	2.10	3.171E+13	7	2.00	2.50	3.205E+13	2.024E+13	1.181E+13
7	2.20	2.40	6.281E+11	2.30	2.731E+11	6	2.50	3.00	1.363E+11	8.609E+10	5.022E+10
6	2.40	2.60	3.253E+11	2.50	1.301E+11	5	3.00	4.00	1.331E+10	8.409E+09	4.905E+09
5	2.60	3.00	1.995E+11	2.80	7.124E+10	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	4.660E+10	3.50	1.331E+10	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	2.009E+15		3.765E+15		0.01	10.00	3.765E+15	2.378E+15	1.387E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-20

fission product decay spectra at cooling time of 1.2614E+08 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 4 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	2.434E+13	0.05	4.869E+14	18	0.01	0.05	2.434E+14	1.537E+14	8.968E+13
18	0.10	0.20	4.104E+13	0.15	2.736E+14	17	0.05	0.10	2.434E+14	1.537E+14	8.968E+13
17	0.20	0.40	5.568E+11	0.30	1.856E+12	16	0.10	0.20	2.736E+14	1.728E+14	1.008E+14
16	0.40	0.60	5.721E+13	0.50	1.144E+14	15	0.20	0.30	9.280E+11	5.861E+11	3.419E+11
15	0.60	0.80	1.687E+15	0.70	2.410E+15	14	0.30	0.40	9.280E+11	5.861E+11	3.419E+11
14	0.80	1.00	1.694E+12	0.90	1.882E+12	13	0.40	0.60	1.144E+14	7.226E+13	4.215E+13
13	1.00	1.20	9.331E+12	1.10	8.482E+12	12	0.60	0.80	2.410E+15	1.522E+15	8.878E+14
12	1.20	1.40	3.413E+11	1.30	2.625E+11	11	0.80	1.00	1.882E+12	1.189E+12	6.934E+11
11	1.40	1.60	1.248E+13	1.50	8.320E+12	10	1.00	1.33	8.653E+12	5.465E+12	3.188E+12
10	1.60	1.80	5.345E+11	1.70	3.144E+11	9	1.33	1.66	8.506E+12	5.372E+12	3.134E+12
9	1.80	2.00	2.923E+11	1.90	1.539E+11	8	1.66	2.00	3.739E+11	2.362E+11	1.378E+11
8	2.00	2.20	4.268E+13	2.10	2.032E+13	7	2.00	2.50	2.056E+13	1.299E+13	7.576E+12
7	2.20	2.40	4.458E+11	2.30	1.938E+11	6	2.50	3.00	9.625E+10	6.079E+10	3.546E+10
6	2.40	2.60	2.309E+11	2.50	9.235E+10	5	3.00	4.00	9.449E+09	5.968E+09	3.481E+09
5	2.60	3.00	1.402E+11	2.80	5.008E+10	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	3.307E+10	3.50	9.449E+09	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	1.878E+15		3.327E+15		0.01	10.00	3.327E+15	2.101E+15	1.226E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-12

fission product decay spectra at cooling time of 2.0736E+07 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 240 days

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	3.381E+14	0.05	6.761E+15	18	0.01	0.05	3.381E+15	2.135E+15	1.245E+15
18	0.10	0.20	9.889E+14	0.15	6.593E+15	17	0.05	0.10	3.381E+15	2.135E+15	1.245E+15
17	0.20	0.40	2.296E+13	0.30	7.653E+13	16	0.10	0.20	6.593E+15	4.164E+15	2.429E+15
16	0.40	0.60	1.959E+15	0.50	3.917E+15	15	0.20	0.30	3.827E+13	2.417E+13	1.410E+13
15	0.60	0.80	6.674E+16	0.70	9.534E+16	14	0.30	0.40	3.827E+13	2.417E+13	1.410E+13
14	0.80	1.00	1.915E+13	0.90	2.128E+13	13	0.40	0.60	3.917E+15	2.474E+15	1.443E+15
13	1.00	1.20	9.223E+13	1.10	8.384E+13	12	0.60	0.80	9.534E+16	6.022E+16	3.513E+16
12	1.20	1.40	7.926E+13	1.30	6.097E+13	11	0.80	1.00	2.128E+13	1.344E+13	7.839E+12
11	1.40	1.60	2.441E+14	1.50	1.628E+14	10	1.00	1.33	1.235E+14	7.798E+13	4.549E+13
10	1.60	1.80	5.321E+12	1.70	3.130E+12	9	1.33	1.66	1.850E+14	1.169E+14	6.817E+13
9	1.80	2.00	2.982E+12	1.90	1.570E+12	8	1.66	2.00	3.761E+12	2.375E+12	1.386E+12
8	2.00	2.20	8.356E+14	2.10	3.979E+14	7	2.00	2.50	4.003E+14	2.529E+14	1.475E+14
7	2.20	2.40	4.458E+12	2.30	1.938E+12	6	2.50	3.00	1.030E+12	6.507E+11	3.796E+11
6	2.40	2.60	2.452E+12	2.50	9.806E+11	5	3.00	4.00	9.442E+10	5.963E+10	3.479E+10
5	2.60	3.00	1.512E+12	2.80	5.400E+11	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	3.305E+11	3.50	9.442E+10	3	5.00	6.50	1.644E-06	1.038E-06	6.056E-07
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	9.040E-06	5.50	1.644E-06	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	7.134E+16		1.134E+17		0.01	10.00	1.134E+17	7.164E+16	4.179E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-10

fission product decay spectra at cooling time of 1.0886E+07 seconds time= 126 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	6.382E+14	0.05	1.276E+16	18	0.01	0.05	6.382E+15	4.031E+15	2.351E+15
18	0.10	0.20	3.166E+15	0.15	2.111E+16	17	0.05	0.10	6.382E+15	4.031E+15	2.351E+15
17	0.20	0.40	1.400E+14	0.30	4.665E+14	16	0.10	0.20	2.111E+16	1.333E+16	7.776E+15
16	0.40	0.60	1.231E+16	0.50	2.461E+16	15	0.20	0.30	2.333E+14	1.473E+14	8.593E+13
15	0.60	0.80	1.921E+17	0.70	2.744E+17	14	0.30	0.40	2.333E+14	1.473E+14	8.593E+13
14	0.80	1.00	3.161E+14	0.90	3.513E+14	13	0.40	0.60	2.461E+16	1.555E+16	9.068E+15
13	1.00	1.20	1.238E+14	1.10	1.126E+14	12	0.60	0.80	2.744E+17	1.733E+17	1.011E+17
12	1.20	1.40	3.028E+14	1.30	2.329E+14	11	0.80	1.00	3.513E+14	2.219E+14	1.294E+14
11	1.40	1.60	1.313E+15	1.50	8.753E+14	10	1.00	1.33	2.640E+14	1.667E+14	9.725E+13
10	1.60	1.80	6.744E+12	1.70	3.967E+12	9	1.33	1.66	9.580E+14	6.051E+14	3.530E+14
9	1.80	2.00	5.531E+12	1.90	2.911E+12	8	1.66	2.00	5.688E+12	3.592E+12	2.095E+12
8	2.00	2.20	1.105E+15	2.10	5.263E+14	7	2.00	2.50	5.493E+14	3.469E+14	2.024E+14
7	2.20	2.40	2.033E+13	2.30	8.839E+12	6	2.50	3.00	1.535E+13	9.694E+12	5.655E+12
6	2.40	2.60	7.090E+13	2.50	2.836E+13	5	3.00	4.00	2.930E+11	1.850E+11	1.079E+11
5	2.60	3.00	3.272E+12	2.80	1.169E+12	4	4.00	5.00	3.055E-15	1.930E-15	1.126E-15
4	3.00	4.00	1.025E+12	3.50	2.930E+11	3	5.00	6.50	3.115E-02	1.967E-02	1.148E-02
3	4.00	5.00	1.375E-14	4.50	3.055E-15	2	6.50	8.00	4.995E-18	3.155E-18	1.840E-18
2	5.00	6.00	1.713E-01	5.50	3.115E-02	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	5.058E-17	6.75	7.493E-18						
total	0.00	7.50	2.116E+17		3.355E+17		0.01	10.00	3.355E+17	2.119E+17	1.236E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii- 9

fission product decay spectra at cooling time of 7.2576E+06 seconds time= 84 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.160E+15	0.05	2.320E+16	18	0.01	0.05	1.160E+16	7.325E+15	4.273E+15
18	0.10	0.20	6.704E+15	0.15	4.470E+16	17	0.05	0.10	1.160E+16	7.325E+15	4.273E+15
17	0.20	0.40	8.038E+14	0.30	2.679E+15	16	0.10	0.20	4.470E+16	2.823E+16	1.647E+16
16	0.40	0.60	2.736E+16	0.50	5.472E+16	15	0.20	0.30	1.340E+15	8.461E+14	4.936E+14
15	0.60	0.80	2.744E+17	0.70	3.920E+17	14	0.30	0.40	1.340E+15	8.461E+14	4.936E+14
14	0.80	1.00	2.492E+15	0.90	2.769E+15	13	0.40	0.60	5.472E+16	3.456E+16	2.016E+16
13	1.00	1.20	1.699E+14	1.10	1.544E+14	12	0.60	0.80	3.920E+17	2.476E+17	1.444E+17
12	1.20	1.40	5.033E+14	1.30	3.871E+14	11	0.80	1.00	2.769E+15	1.749E+15	1.020E+15
11	1.40	1.60	1.121E+16	1.50	7.474E+15	10	1.00	1.33	4.061E+14	2.565E+14	1.496E+14
10	1.60	1.80	7.532E+12	1.70	4.430E+12	9	1.33	1.66	7.611E+15	4.807E+15	2.804E+15
9	1.80	2.00	1.948E+13	1.90	1.025E+13	8	1.66	2.00	1.335E+13	8.433E+12	4.919E+12
8	2.00	2.20	1.229E+15	2.10	5.850E+14	7	2.00	2.50	7.843E+14	4.953E+14	2.890E+14
7	2.20	2.40	1.491E+14	2.30	6.483E+13	6	2.50	3.00	1.399E+14	8.835E+13	5.154E+13
6	2.40	2.60	6.723E+14	2.50	2.689E+14	5	3.00	4.00	1.774E+12	1.120E+12	6.536E+11
5	2.60	3.00	1.519E+13	2.80	5.423E+12	4	4.00	5.00	1.026E-08	6.481E-09	3.781E-09
4	3.00	4.00	6.209E+12	3.50	1.774E+12	3	5.00	6.50	1.173E+00	7.410E-01	4.323E-01
3	4.00	5.00	4.618E-08	4.50	1.026E-08	2	6.50	8.00	2.650E-11	1.674E-11	9.765E-12
2	5.00	6.00	6.453E+00	5.50	1.173E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	2.683E-10	6.75	3.975E-11						
total	0.00	7.50	3.269E+17		5.290E+17		0.01	10.00	5.290E+17	3.341E+17	1.949E+17

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-11

fission product decay spectra at cooling time of 1.5552E+07 seconds time= 180 days
following shutdown calculated with pulse function fits to results of
cinder-10 endf/b-v summation calculations and limited experimental data

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	4.265E+14	0.05	8.531E+15	18	0.01	0.05	4.265E+15	2.694E+15	1.571E+15
18	0.10	0.20	1.562E+15	0.15	1.041E+16	17	0.05	0.10	4.265E+15	2.694E+15	1.571E+15
17	0.20	0.40	4.596E+13	0.30	1.532E+14	16	0.10	0.20	1.041E+16	6.576E+15	3.836E+15
16	0.40	0.60	4.887E+15	0.50	9.773E+15	15	0.20	0.30	7.660E+13	4.838E+13	2.822E+13
15	0.60	0.80	1.176E+17	0.70	1.681E+17	14	0.30	0.40	7.660E+13	4.838E+13	2.822E+13
14	0.80	1.00	4.088E+13	0.90	4.542E+13	13	0.40	0.60	9.773E+15	6.173E+15	3.601E+15
13	1.00	1.20	1.046E+14	1.10	9.512E+13	12	0.60	0.80	1.681E+17	1.061E+17	6.192E+16
12	1.20	1.40	1.592E+14	1.30	1.225E+14	11	0.80	1.00	4.542E+13	2.869E+13	1.673E+13
11	1.40	1.60	3.247E+14	1.50	2.165E+14	10	1.00	1.33	1.747E+14	1.104E+14	6.438E+13
10	1.60	1.80	5.997E+12	1.70	3.528E+12	9	1.33	1.66	2.604E+14	1.645E+14	9.594E+13
9	1.80	2.00	3.455E+12	1.90	1.818E+12	8	1.66	2.00	4.288E+12	2.708E+12	1.580E+12
8	2.00	2.20	9.676E+14	2.10	4.608E+14	7	2.00	2.50	4.645E+14	2.934E+14	1.711E+14
7	2.20	2.40	5.803E+12	2.30	2.523E+12	6	2.50	3.00	1.877E+12	1.185E+12	6.914E+11
6	2.40	2.60	6.215E+12	2.50	2.486E+12	5	3.00	4.00	1.164E+11	7.353E+10	4.289E+10
5	2.60	3.00	1.775E+12	2.80	6.339E+11	4	4.00	5.00	1.243E-23	7.848E-24	4.578E-24
4	3.00	4.00	4.075E+11	3.50	1.164E+11	3	5.00	6.50	2.932E-04	1.852E-04	1.080E-04
3	4.00	5.00	5.592E-23	4.50	1.243E-23	2	6.50	8.00	1.194E-26	7.544E-27	4.401E-27
2	5.00	6.00	1.613E-03	5.50	2.932E-04	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	1.209E-25	6.75	1.792E-26						
total	0.00	7.50	1.262E+17		1.979E+17		0.01	10.00	1.979E+17	1.250E+17	7.290E+16

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-21

fission product decay spectra at cooling time of 1.4191E+08 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 4.5 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.899E+13	0.05	3.797E+14	18	0.01	0.05	1.899E+14	1.199E+14	6.995E+13
18	0.10	0.20	2.689E+13	0.15	1.792E+14	17	0.05	0.10	1.899E+14	1.199E+14	6.995E+13
17	0.20	0.40	4.847E+11	0.30	1.616E+12	16	0.10	0.20	1.792E+14	1.132E+14	6.604E+13
16	0.40	0.60	4.275E+13	0.50	8.549E+13	15	0.20	0.30	8.078E+11	5.102E+11	2.976E+11
15	0.60	0.80	1.651E+15	0.70	2.359E+15	14	0.30	0.40	8.078E+11	5.102E+11	2.976E+11
14	0.80	1.00	1.200E+12	0.90	1.334E+12	13	0.40	0.60	8.549E+13	5.400E+13	3.150E+13
13	1.00	1.20	6.628E+12	1.10	6.026E+12	12	0.60	0.80	2.359E+15	1.490E+15	8.691E+14
12	1.20	1.40	2.280E+11	1.30	1.754E+11	11	0.80	1.00	1.334E+12	8.422E+11	4.913E+11
11	1.40	1.60	8.128E+12	1.50	5.418E+12	10	1.00	1.33	6.140E+12	3.878E+12	2.262E+12
10	1.60	1.80	3.792E+11	1.70	2.231E+11	9	1.33	1.66	5.547E+12	3.503E+12	2.044E+12
9	1.80	2.00	2.066E+11	1.90	1.087E+11	8	1.66	2.00	2.649E+11	1.673E+11	9.759E+10
8	2.00	2.20	2.736E+13	2.10	1.303E+13	7	2.00	2.50	1.320E+13	8.335E+12	4.862E+12
7	2.20	2.40	3.164E+11	2.30	1.375E+11	6	2.50	3.00	6.800E+10	4.295E+10	2.505E+10
6	2.40	2.60	1.639E+11	2.50	6.554E+10	5	3.00	4.00	6.706E+09	4.236E+09	2.471E+09
5	2.60	3.00	9.863E+10	2.80	3.523E+10	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	2.347E+10	3.50	6.706E+09	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	1.785E+15		3.032E+15		0.01	10.00	3.032E+15	1.915E+15	1.117E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

table vii-22

fission product decay spectra at cooling time of 1.5768E+08 seconds following shutdown calculated with pulse function fits to results of cinder-10 endf/b-v summation calculations and limited experimental data

time= 5 years

19 groups	emin, mev	emax, mev	total mev/s	Avg. group energy Mev	total flux photons/s	18 groups	emin, mev	emax, mev	total flux photons/s	Upper Fuel total flux photons/s	Lower Fuel total flux photons/s
19	0.00	0.10	1.547E+13	0.05	3.093E+14	18	0.01	0.05	1.547E+14	9.769E+13	5.698E+13
18	0.10	0.20	1.784E+13	0.15	1.189E+14	17	0.05	0.10	1.547E+14	9.769E+13	5.698E+13
17	0.20	0.40	4.223E+11	0.30	1.408E+12	16	0.10	0.20	1.189E+14	7.511E+13	4.382E+13
16	0.40	0.60	3.235E+13	0.50	6.470E+13	15	0.20	0.30	7.038E+11	4.445E+11	2.593E+11
15	0.60	0.80	1.621E+15	0.70	2.315E+15	14	0.30	0.40	7.038E+11	4.445E+11	2.593E+11
14	0.80	1.00	8.518E+11	0.90	9.465E+11	13	0.40	0.60	6.470E+13	4.086E+13	2.384E+13
13	1.00	1.20	4.709E+12	1.10	4.281E+12	12	0.60	0.80	2.315E+15	1.462E+15	8.530E+14
12	1.20	1.40	1.542E+11	1.30	1.186E+11	11	0.80	1.00	9.465E+11	5.978E+11	3.487E+11
11	1.40	1.60	5.308E+12	1.50	3.538E+12	10	1.00	1.33	4.358E+12	2.752E+12	1.606E+12
10	1.60	1.80	2.691E+11	1.70	1.583E+11	9	1.33	1.66	3.627E+12	2.291E+12	1.336E+12
9	1.80	2.00	1.460E+11	1.90	7.685E+10	8	1.66	2.00	1.876E+11	1.185E+11	6.913E+10
8	2.00	2.20	1.754E+13	2.10	8.350E+12	7	2.00	2.50	8.471E+12	5.350E+12	3.121E+12
7	2.20	2.40	2.245E+11	2.30	9.761E+10	6	2.50	3.00	4.806E+10	3.035E+10	1.771E+10
6	2.40	2.60	1.163E+11	2.50	4.652E+10	5	3.00	4.00	4.760E+09	3.006E+09	1.754E+09
5	2.60	3.00	6.944E+10	2.80	2.480E+10	4	4.00	5.00	0.000E+00	0.000E+00	0.000E+00
4	3.00	4.00	1.666E+10	3.50	4.760E+09	3	5.00	6.50	0.000E+00	0.000E+00	0.000E+00
3	4.00	5.00	0.000E+00	4.50	0.000E+00	2	6.50	8.00	0.000E+00	0.000E+00	0.000E+00
2	5.00	6.00	0.000E+00	5.50	0.000E+00	1	8.00	10.00	0	0.000E+00	0.000E+00
1	6.00	7.50	0.000E+00	6.75	0.000E+00						
total	0.00	7.50	1.716E+15		2.827E+15		0.01	10.00	2.827E+15	1.786E+15	1.042E+15

* the sum of beta and gamma group spectra may differ slightly from total decay power calculated in table iv for this cooling time. spectra do not include the effects of neutron absorption.

Appendix C: SCALE Input Files

```
//D2OPOOL1 JOB ,BOLOGNA,GROUP=J62785,USER=P89739,MSGLEVEL=(1,1),
// TIME=60,NOTIFY=P89739,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BOLOGNA
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
ANS FUEL ELEMENT (HOMOGENIZED FUEL-UFE+LFE) 1 DAY OUT OF CORE - D20 POOL
'NON-SOURCE ELEMENTS ARE WATER
18GROUPGAMMA INFHOMMEDIUM
  U-233        1   0.0    1.15983E-15     317   END
  U-234        1   0.0    6.60430E-06     317   END
  U-235        1   0.0    5.82311E-04     317   END
  U-236        1   0.0    2.66836E-06     317   END
  U-238        1   0.0    3.27635E-05     317   END
  SI           1   0.0    4.15914E-04     317   END
  MG        1   0.0    1.3374267E-04     317   END
  AL        1   0.0    2.7905164E-02     317   END
  SI        1   0.0    1.4059918E-04     317   END
  TI        1   0.0    1.0183909E-05     317   END
  CR        1   0.0    1.2503453E-05     317   END
  MN        1   0.0    1.2917070E-05     317   END
  FE        1   0.0    8.0506777E-05     317   END
  ZN        1   0.0    2.2142766E-05     317   END
  ZN        1   0.0    1.9222156E-05     317   END
  D      1   0.0    2.94852E-02    317   END
  O      1   0.0    1.47426E-02    317   END
  H      1   0.0    1.00000E-15    317   END
  O      1   0.0    1.00000E-15    317   END
  B4C    1     1.00000E-15       317   END
H         2 0   6.686-3    317  END
O         2 0   3.343-2    317  END
H         3 0   1.402-2    317  END
O         3 0   4.654-2    317  END
NA        3 0   9.822-4    317  END
AL        3 0   1.776-3    317  END
SI        3 0   1.869-2    317  END
CA        3 0   1.545-3    317  END
FE        3 0   3.522-4    317  END
FE        4 0   5.9788-2   317  END
CR        4 0   1.8347-2   317  END
NI        4 0   8.1250-3   317  END
MG        5   0.0    6.68713E-04     317   END
AL        5   0.0    5.82195E-02     317   END
SI        5   0.0    3.47224E-04     317   END
TI        5   0.0    5.09195E-05     317   END
CR        5   0.0    6.25173E-05     317   END
MN        5   0.0    4.43768E-05     317   END
FE        5   0.0    2.03729E-04     317   END
ZN        5   0.0    7.60718E-05     317   END
ZN        5   0.0    6.21488E-05     317   END
D         6   0.0    5.956-2         317   END
O         6   0.0    2.978-2         317   END
   END COMP
 SHIELDING PROBLEM
 NOD=2 RAN=D9A1B6E99B63 NOP=3 NIT=1000 MSM=1 END
9.0+6    7.25+6    5.75+6    4.55+6    3.55+6    2.75+6
```

```
2.25+6    1.83+6     1.495+6     1.165+6    0.9+6      7.0+5
5.0+5     3.5+5      2.5+5       1.5+5      0.75+5     3.0+4
146250    123250     100625      85313      71000      59125
49500     44835      38123       31455      25650      20300
14750     10150      7250        4838       10125      127000
6.1-12      6.2-12       8.36-12   1.3933-11   1.9427-11
2.5876-11  3.3599-11   4.0486-11 5.0666-11   5.8027-11
6.6162-11  7.5637-11   8.7580-11 1.0231-10   1.2022-10
1.4092-10  1.6561-10   1.9427-10
ENERGY FLUX DENSITY
TYPE 04 CONCRETE DOSE FACTORS
ANSI PHOTON RESPONSE FOR PHANTOM RELATED DOSE EQUIVALENT
 SHIELDING PROBLEM
 0 0 0 0
  RPP     -176.6     176.6    -609.6    609.6    -204.2     0.0
  RPP     -176.6     176.6    -609.6    609.6       0.0   832.1
  RPP     -176.6     176.6    -609.6    304.8    -234.7  -204.2
  RPP     -200.0     200.0    -650.0    650.0    -250.0   900.0
  RPP     -300.0     300.0    -700.0    700.0    -300.0  1000.0
  RCC        0.0         0.0         0.0       0.0        0.0      52.7
           24.2
  RCC        0.0         0.0         0.0       0.0        0.0      52.7
           9.5
  RCC        0.0         0.0         0.0       0.0        0.0      52.7
           10.2
  RCC     0.0            0.0         0.0       0.0        0.0      52.7
           16.8
  RCC     0.0            0.0         0.0       0.0        0.0      52.7
           17.5
  RCC     0.0            0.0         0.0       0.0        0.0      52.7
           23.5
    END
 H2O    1
 D2O    2 -6
 CON    3
 VIN    4 -3 -2 -1 -6
 VOT    5 -4
 CTV    7
 INW    8 -7
 INF    9 -8
 CTW   10 -9
 OTF   11 -10
 OTW    6 -11
    END
    2     2     2     2     2     1     1
    1     1     1     1
11*0
    2     6     3   1000     0    0    5    1
    5     1     5
 0
150.0 2*0.0 -25.0 25.0 -25.0 25.0  0.0  52.7
36*1
0.0       5.501+2    9.828+3    1.761+12   1.528+14   1.204+16
2.471+16 2.371+16   6.313+17   1.375+17   3.838+17   1.975+18
1.231+18 5.002+17   5.002+17   7.327+17   6.543+17   6.543+17   1.0
  0.0       0.0     832.1
  0.0       0.0    -204.22
END
```

```
//INT21 JOB ,BOLOGNA,GROUP=J62785,USER=P89739,MSGLEVEL=(1,1),
// TIME=50,NOTIFY=P89739,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BOLOGNA
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
ANS FUEL ELEMENT (HOMOGENIZED FUEL-UFE+LFE) 21 DAYS OUT OF CORE - 4 FT H2O
'NON-SOURCE ELEMENTS ARE HOMOGENIZED FUEL
18GROUPGAMMA INFHOMMEDIUM
  U-233        1   0.0    1.15983E-15     317   END
  U-234        1   0.0    6.60430E-06     317   END
  U-235        1   0.0    5.82311E-04     317   END
  U-236        1   0.0    2.66836E-06     317   END
  U-238        1   0.0    3.27635E-05     317   END
  SI           1   0.0    4.15914E-04     317   END
  MG       1   0.0    1.3374267E-04     317   END
  AL       1   0.0    2.7905164E-02     317   END
  SI       1   0.0    1.4059918E-04     317   END
  TI       1   0.0    1.0183909E-05     317   END
  CR       1   0.0    1.2503453E-05     317   END
  MN       1   0.0    1.2917070E-05     317   END
  FE       1   0.0    8.0506777E-05     317   END
  ZN       1   0.0    2.2142766E-05     317   END
  ZN       1   0.0    1.9222156E-05     317   END
  D      1   0.0    2.94852E-02    317   END
  O      1   0.0    1.47426E-02    317   END
  H      1   0.0    1.00000E-15    317   END
  O      1   0.0    1.00000E-15    317   END
  B4C    1      1.00000E-15       317   END
H         2 0   6.686-3    317  END
O         2 0   3.343-2    317  END
H         3 0   1.402-2    317  END
O         3 0   4.654-2    317  END
NA        3 0   9.822-4    317  END
AL        3 0   1.776-3    317  END
SI        3 0   1.869-2    317  END
CA        3 0   1.545-3    317  END
FE        3 0   3.522-4    317  END
FE        4 0   5.9788-2   317  END
CR        4 0   1.8347-2   317  END
NI        4 0   8.1250-3   317  END
MG        5   0.0    6.68713E-04     317   END
AL        5   0.0    5.82195E-02     317   END
SI        5   0.0    3.47224E-04     317   END
TI        5   0.0    5.09195E-05     317   END
CR        5   0.0    6.25173E-05     317   END
MN        5   0.0    4.43768E-05     317   END
FE        5   0.0    2.03729E-04     317   END
ZN        5   0.0    7.60718E-05     317   END
ZN        5   0.0    6.21488E-05     317   END
   END COMP
 SHIELDING PROBLEM
 NOD=1 RAN=43DBA07EB20F NOP=2 NIT=1000 MSM=1 END
9.0+6    7.25+6    5.75+6    4.55+6    3.55+6    2.75+6
2.25+6   1.83+6    1.495+6   1.165+6   0.9+6     7.0+5
5.0+5    3.5+5     2.5+5     1.5+5     0.75+5    3.0+4
```

```
146250   123250    100625    85313     71000     59125
49500    44835     38123     31455     25650     20300
14750    10150     7250      4838      10125     127000
ENERGY FLUX DENSITY
TYPE 04 CONCRETE DOSE FACTORS
 SHIELDING PROBLEM
 0 0 0 0
  RPP    -150.000    650.000   -167.075  570.00   -192.4     700.
  RPP    -150.000    650.000   -146.120  570.00   -152.4     700.
  RPP    -150.000    650.000   -145.485  570.00   -151.765   700.
  RPP   -1000.       1000.     -1000.    1000.    -1000.     1000.
  RPP   -2000.       2000.     -2000.    2000.    -2000.     2000.
  RCC       0.0        0.0       0.0       0.0       0.0     52.7
          24.2
  RCC       0.0        0.0       0.0       0.0       0.0     52.7
          9.5
  RCC       0.0      126.86      0.0       0.0       0.0     52.7
          24.2
  RCC       0.0      126.86      0.0       0.0       0.0     52.7
          9.5
  RCC       0.0      277.9       0.0       0.0       0.0     52.7
          24.2
  RCC       0.0      277.9       0.0       0.0       0.0     52.7
          9.5
  RCC    103.665       0.0       0.0       0.0       0.0     52.7
          24.2
  RCC    103.665       0.0       0.0       0.0       0.0     52.7
          9.5
  RCC    103.665    126.86       0.0       0.0       0.0     52.7
          24.2
  RCC    103.665    126.86       0.0       0.0       0.0     52.7
          9.5
  RCC    103.665    277.9        0.0       0.0       0.0     52.7
          24.2
  RCC    103.665    277.9        0.0       0.0       0.0     52.7
          9.5
  RCC    207.33        0.0       0.0       0.0       0.0     52.7
          24.2
  RCC    207.33        0.0       0.0       0.0       0.0     52.7
          9.5
  RCC    207.33     103.86       0.0       0.0       0.0     52.7
          24.2
  RCC    207.33     103.86       0.0       0.0       0.0     52.7
          9.5
  RCC    207.33     277.9        0.0       0.0       0.0     52.7
          24.2
  RCC    207.33     277.9        0.0       0.0       0.0     52.7
          9.5
  RCC    310.995       0.0       0.0       0.0       0.0     52.7
          24.2
  RCC    310.995       0.0       0.0       0.0       0.0     52.7
          9.5
  RCC    310.995    103.86       0.0       0.0       0.0     52.7
          24.2
  RCC    310.995    103.86       0.0       0.0       0.0     52.7
          9.5
  RCC    310.995    277.9        0.0       0.0       0.0     52.7
          24.2
  RCC    310.995    277.9        0.0       0.0       0.0     52.7
          9.5
```

```
  RCC     414.66          0.0          0.0       0.0         0.0      52.7
            24.2
  RCC     414.66          0.0          0.0       0.0         0.0      52.7
            9.5
  RCC     414.66       103.86          0.0       0.0         0.0      52.7
            24.2
  RCC     414.66       103.86          0.0       0.0         0.0      52.7
            9.5
  RCC     414.66       277.9           0.0       0.0         0.0      52.7
            24.2
  RCC     414.66       277.9           0.0       0.0         0.0      52.7
            9.5
  RCC     518.3           0.0          0.0       0.0         0.0      52.7
            24.2
  RCC     518.3           0.0          0.0       0.0         0.0      52.7
            9.5
  RCC     518.3        103.86          0.0       0.0         0.0      52.7
            24.2
  RCC     518.3        103.86          0.0       0.0         0.0      52.7
            9.5
  RCC     518.3        277.9           0.0       0.0         0.0      52.7
            24.2
  RCC     518.3        277.9           0.0       0.0         0.0      52.7
            9.5
  RCC     0.0             0.0          0.0       0.0         0.0      52.7
            10.2
  RCC     0.0             0.0          0.0       0.0         0.0      52.7
            16.8
  RCC     0.0             0.0          0.0       0.0         0.0      52.7
            17.5
  RCC     0.0             0.0          0.0       0.0         0.0      52.7
            23.5
  RCC     0.0             0.0          0.0       0.0         0.0      52.70
            24.2
    END
  H2O             3      -6      -8     -12     -14     -18
                -20     -24     -26     -30     -32     -36  -38
  LIN      OR     2      -3
  CON      OR     1      -2
  VID             4      -1
  VIX             5      -4
  HIF      OR    40     -41OR    8     -9OR    10    -11OR    12    -13OR    14
                -15OR    16     -17OR   18     -19OR   20     -21OR   22     -23
           OR    24     -25OR   26     -27OR   28     -29OR   30     -31OR   32
                -33OR    34     -35OR   36     -37OR   38     -39
  COR      OR    7OR    9OR    11OR    13OR    15OR    17OR    19OR    21OR    23
           OR    25OR   27OR    29OR    31OR    33OR    35OR    37OR    39OR    41
           OR    10OR   16OR    22OR    28OR    34OR    40
  INW             42     -7
  CTW             44     -43
  OTW             46     -45
  INF             43     -42
  OTF             45     -44
    END
    2    2    2    2    2    2    2    1
    1    2    1    1
12*0
    2    4    3   1000    0   1    2   5
    5    5    1    1
 0
```

```
150.0 2*0.0 -25.0 25.0 -25.0 25.0  0.0  52.7
36*1
0.0       3.397-1   2.726+2   6.321+1    5.121+13   4.347+15
6.948+15 2.658+14  2.196+17  2.479+15   8.545+16   6.258+17
3.404+17 5.745+16  5.745+16  1.719+17   9.127+16   9.127+16  1.0
  0.0       -146.755     26.35
END
```

```
//RBSFSP1 JOB ,BOLOGNA,GROUP=J62785,USER=P89739,MSGLEVEL=(1,1),
// TIME=150,NOTIFY=P89739,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BOLOGNA
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
ANS FUEL ELEMENT (HOMOGENIZED FUEL-UFE+LFE) 1 DAY OUT OF CORE - 4 FT H2O
'NON-SOURCE ELEMENTS ARE HOMOGENIZED FUEL
18GROUPGAMMA INFHOMMEDIUM
  U-233        1   0.0    1.15983E-15     317   END
  U-234        1   0.0    6.60430E-06     317   END
  U-235        1   0.0    5.82311E-04     317   END
  U-236        1   0.0    2.66836E-06     317   END
  U-238        1   0.0    3.27635E-05     317   END
  SI           1   0.0    4.15914E-04     317   END
  MG       1   0.0    1.3374267E-04     317   END
  AL       1   0.0    2.7905164E-02     317   END
  SI       1   0.0    1.4059918E-04     317   END
  TI       1   0.0    1.0183909E-05     317   END
  CR       1   0.0    1.2503453E-05     317   END
  MN       1   0.0    1.2917070E-05     317   END
  FE       1   0.0    8.0506777E-05     317   END
  ZN       1   0.0    2.2142766E-05     317   END
  ZN       1   0.0    1.9222156E-05     317   END
  D      1   0.0    2.94852E-02    317   END
  O      1   0.0    1.47426E-02    317   END
  H      1   0.0    1.00000E-15    317   END
  O      1   0.0    1.00000E-15    317   END
  B4C    1      1.00000E-15        317   END
H         2 0   6.686-3    317  END
O         2 0   3.343-2    317  END
H         3 0   1.402-2    317  END
O         3 0   4.654-2    317  END
NA        3 0   9.822-4    317  END
AL        3 0   1.776-3    317  END
SI        3 0   1.869-2    317  END
CA        3 0   1.545-3    317  END
FE        3 0   3.522-4    317  END
FE        4 0   5.9788-2   317  END
CR        4 0   1.8347-2   317  END
NI        4 0   8.1250-3   317  END
MG        5   0.0    6.68713E-04     317   END
AL        5   0.0    5.82195E-02     317   END
SI        5   0.0    3.47224E-04     317   END
TI        5   0.0    5.09195E-05     317   END
CR        5   0.0    6.25173E-05     317   END
MN        5   0.0    4.43768E-05     317   END
FE        5   0.0    2.03729E-04     317   END
ZN        5   0.0    7.60718E-05     317   END
ZN        5   0.0    6.21488E-05     317   END
   END COMP
 SHIELDING PROBLEM
 NOD=6 RAN=435C2B239D27 NOP=2 NIT=800 MSM=1 END
9.0+6    7.25+6    5.75+6    4.55+6    3.55+6    2.75+6
2.25+6   1.83+6    1.495+6   1.165+6   0.9+6     7.0+5
5.0+5    3.5+5     2.5+5     1.5+5     0.75+5    3.0+4
```

```
146250   123250    100625    85313     71000     59125
49500    44835     38123     31455     25650     20300
14750    10150     7250      4838      10125     127000
ENERGY FLUX DENSITY
TYPE 04 CONCRETE DOSE FACTORS
 SHIELDING PROBLEM
 0 0 0 0
  RPP    -150.000    650.000   -167.075  570.00   -192.4     700.
  RPP    -150.000    650.000   -146.120  570.00   -152.4     700.
  RPP    -150.000    650.000   -145.485  570.00   -151.765   700.
  RPP   -1000.       1000.     -1000.    1000.    -1000.     1000.
  RPP   -2000.       2000.     -2000.    2000.    -2000.     2000.
  RCC       0.0        0.0       0.0       0.0       0.0     52.7
          24.2
  RCC       0.0        0.0       0.0       0.0       0.0     52.7
          9.5
  RCC       0.0     126.86       0.0       0.0       0.0     52.7
          24.2
  RCC       0.0     126.86       0.0       0.0       0.0     52.7
          9.5
  RCC       0.0      277.9       0.0       0.0       0.0     52.7
          24.2
  RCC       0.0      277.9       0.0       0.0       0.0     52.7
          9.5
  RCC   103.665        0.0       0.0       0.0       0.0     52.7
          24.2
  RCC   103.665        0.0       0.0       0.0       0.0     52.7
          9.5
  RCC   103.665     126.86       0.0       0.0       0.0     52.7
          24.2
  RCC   103.665     126.86       0.0       0.0       0.0     52.7
          9.5
  RCC   103.665      277.9       0.0       0.0       0.0     52.7
          24.2
  RCC   103.665      277.9       0.0       0.0       0.0     52.7
          9.5
  RCC   207.33         0.0       0.0       0.0       0.0     52.7
          24.2
  RCC   207.33         0.0       0.0       0.0       0.0     52.7
          9.5
  RCC   207.33      103.86       0.0       0.0       0.0     52.7
          24.2
  RCC   207.33      103.86       0.0       0.0       0.0     52.7
          9.5
  RCC   207.33      277.9       0.0       0.0       0.0     52.7
          24.2
  RCC   207.33      277.9       0.0       0.0       0.0     52.7
          9.5
  RCC   310.995        0.0       0.0       0.0       0.0     52.7
          24.2
  RCC   310.995        0.0       0.0       0.0       0.0     52.7
          9.5
  RCC   310.995     103.86       0.0       0.0       0.0     52.7
          24.2
  RCC   310.995     103.86       0.0       0.0       0.0     52.7
          9.5
  RCC   310.995      277.9       0.0       0.0       0.0     52.7
          24.2
  RCC   310.995      277.9       0.0       0.0       0.0     52.7
          9.5
```

```
  RCC     414.66          0.0          0.0        0.0          0.0       52.7
            24.2
  RCC     414.66          0.0          0.0        0.0          0.0       52.7
            9.5
  RCC     414.66       103.86          0.0        0.0          0.0       52.7
            24.2
  RCC     414.66       103.86          0.0        0.0          0.0       52.7
            9.5
  RCC     414.66       277.9           0.0        0.0          0.0       52.7
            24.2
  RCC     414.66       277.9           0.0        0.0          0.0       52.7
            9.5
  RCC     518.3           0.0          0.0        0.0          0.0       52.7
            24.2
  RCC     518.3           0.0          0.0        0.0          0.0       52.7
            9.5
  RCC     518.3        103.86          0.0        0.0          0.0       52.7
            24.2
  RCC     518.3        103.86          0.0        0.0          0.0       52.7
            9.5
  RCC     518.3        277.9           0.0        0.0          0.0       52.7
            24.2
  RCC     518.3        277.9           0.0        0.0          0.0       52.7
            9.5
  RCC     0.0             0.0          0.0        0.0          0.0       52.7
            10.2
  RCC     0.0             0.0          0.0        0.0          0.0       52.7
            16.8
  RCC     0.0             0.0          0.0        0.0          0.0       52.7
            17.5
  RCC     0.0             0.0          0.0        0.0          0.0       52.7
            23.5
  RCC     0.0             0.0          0.0        0.0          0.0       52.70
            24.2
    END
  H2O           3     -6     -8     -12     -14     -18
               -20    -24    -26     -30     -32     -36  -38
  LIN     OR    2     -3
  CON     OR    1     -2
  VID           4     -1
  VIX           5     -4
  HIF     OR   40    -41OR   8     -9OR   10    -11OR   12    -13OR   14
              -15OR   16    -17OR   18    -19OR   20    -21OR   22    -23
          OR   24    -25OR   26    -27OR   28    -29OR   30    -31OR   32
              -33OR   34    -35OR   36    -37OR   38    -39
  COR     OR   7OR   9OR   11OR   13OR   15OR   17OR   19OR   21OR   23
          OR   25OR 27OR   29OR   31OR   33OR   35OR   37OR   39OR   41
          OR   10OR 16OR   22OR   28OR   34OR   40
  INW           42     -7
  CTW           44     -43
  OTW           46     -45
  INF           43     -42
  OTF           45     -44
    END
    2    2    2    2    2    2    2    1
    1    2    1    1
12*0
    2    4    3   1000    0   1   2   5
    5    5    1    1
 0
```

```
150.0 2*0.0 -25.0 25.0 -25.0 25.0  0.0  52.7
36*1
0.0       5.501+2   9.828+3   1.761+12   1.528+14   1.204+16
2.471+16 2.371+16  6.313+17  1.375+17   3.838+17   1.975+18
1.231+18 5.002+17  5.002+17  7.327+17   6.543+17   6.543+17  1.0
  0.0      -146.755     26.35
  103.665  -146.755     26.35
  207.37   -146.755     26.35
  0.0       297.815     26.35
  100.6     297.815     26.35
  0.0         0.0      -152.45
END
```

```
//ISS2H2 JOB ,BOLOGNA,GROUP=J62785,USER=P89739,MSGLEVEL=(1,1),
// TIME=50,NOTIFY=P89739,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BOLOGNA
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
ANS UPPER ELEMENT (HOMOGENIZED FUEL) 1 DAY OUT OF CORE - DOSE TO MAN AT POOL
18GROUPGAMMA INFHOMMEDIUM
  U-233        1   0.0    1.00000E-15     317   END
  U-234        1   0.0    7.09956E-06     317   END
  U-235        1   0.0    6.25601E-04     317   END
  U-236        1   0.0    2.86555E-06     317   END
  U-238        1   0.0    3.52468E-05     317   END
  SI           1   0.0    4.47209E-04     317   END
  MG        1   0.0    1.3374267E-04      317   END
  AL        1   0.0    2.7905164E-02      317   END
  SI        1   0.0    1.4059918E-04      317   END
  TI        1   0.0    1.0183909E-05      317   END
  CR        1   0.0    1.2503453E-05      317   END
  MN        1   0.0    1.2917070E-05      317   END
  FE        1   0.0    8.0506777E-05      317   END
  ZN        1   0.0    2.2142766E-05      317   END
  ZN        1   0.0    1.9222156E-05      317   END
  D      1   0.0    2.94852E-02    317   END
  O      1   0.0    1.47426E-02    317   END
  H      1   0.0    1.00000E-15    317   END
  O      1   0.0    1.00000E-15    317   END
  B4C    1     1.00000E-15       317   END
H         2 0   6.686-3    317  END
O         2 0   3.343-2    317  END
H         3 0   1.402-2    317  END
O         3 0   4.654-2    317  END
NA        3 0   9.822-4    317  END
AL        3 0   1.776-3    317  END
SI        3 0   1.869-2    317  END
CA        3 0   1.545-3    317  END
FE        3 0   3.522-4    317  END
FE        4 0   5.9788-2   317  END
CR        4 0   1.8347-2   317  END
NI        4 0   8.1250-3   317  END
MG        5   0.0    6.68713E-04     317   END
AL        5   0.0    5.82195E-02     317   END
SI        5   0.0    3.47224E-04     317   END
TI        5   0.0    5.09195E-05     317   END
CR        5   0.0    6.25173E-05     317   END
MN        5   0.0    4.43768E-05     317   END
FE        5   0.0    2.03729E-04     317   END
ZN        5   0.0    7.60718E-05     317   END
ZN        5   0.0    6.21488E-05     317   END
D         6   0.0    5.956-2         317   END
O         6   0.0    2.978-2         317   END
   END COMP
 SHIELDING PROBLEM
 NOD=1 RAN=C6582D3B821B NOP=1 NIT=1000 MSM=1 END
6.1-12     6.2-12      8.36-12   1.3933-11   1.9427-11
2.5876-11  3.3599-11   4.0486-11 5.0666-11   5.8027-11
```

```
6.6162-11  7.5637-11   8.7580-11 1.0231-10   1.2022-10
1.4092-10  1.6561-10   1.9427-10
ANSI PHOTON RESPONSE FOR PHANTOM RELATED DOSE EQUIVALENT
 SHIELDING PROBLEM
 0 0 0 0
  RCC       0.0         0.0       152.4       0.0        0.0     52.7
          9.5
  RCC       0.0         0.0       152.4       0.0        0.0     52.7
          10.2
  RCC     0.0           0.0       152.4       0.0        0.0     52.7
          16.8
  RCC     0.0           0.0       152.4       0.0        0.0     52.7
          17.5
  RCC     0.0           0.0       152.4       0.0        0.0     52.7
          23.5
  RCC     0.0           0.0       152.4       0.0        0.0     52.7
          24.2
  RCC     0.0           0.0      -457.0       0.0        0.0     891.8
          175.0
  RCC     0.0           0.0      -457.0       0.0        0.0     891.8
          175.5
  RCC     0.0           0.0      -457.0       0.0        0.0     891.8
          304.8
  RCC     0.0           0.0      -457.0       0.0        0.0     937.6
          307.34
  RCC     0.0           0.0      -457.0       0.0        0.0     937.6
          396.2
  RPP   -1000.       1000.      -1000.     1000.     -1000.     1000.
  RPP   -2000.       2000.      -2000.     2000.     -2000.     2000.
  RCC     0.0           0.0       434.78       0.0        0.0      45.8
          304.8
    END
  INV    1
  INW    2 -1
  D2O    3 -2
  CTW    4 -3
  FUL    5 -4
  OTW    6 -5
  D2O    7 -6
  STK    8 -7
  H2O    9 -8
  WAL    10 -9 -14
  CON    11 -10
  VIN    12 -11
  VOT    13 -12
  AIR    14
    END
    1     1     1     1     1     2     2     2     2
    2     2     2     2     2
14*0
    1000 5     6     5     1     5     6     5     2
    5     3     1000 0     0
 0
150.0 2*0.0 -25.0 25.0 -25.0 25.0 152.4  205.1
36*1
0.0       3.209+2   5.733+3   1.027+12   8.913+13   7.023+15
1.441+16 1.383+16  3.683+17  8.023+16   2.239+17   1.152+18
7.179+17 2.919+17  2.918+17  4.274+17   3.816+17   3.816+17  1.0
  304.8    0.0      480.5
END
```

```
//ANSR13 JOB ,BOLOGNA,GROUP=J62785,USER=P89739,MSGLEVEL=(1,1),
// TIME=70,NOTIFY=P89739,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BOLOGNA
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
ANS UPPER ELEMENT (HOMOGENIZED FUEL) 1 DAY OUT OF CORE - 3 FT H2O
'NON-SOURCE ELEMENTS (UFE+LFE) ARE EACH HOMOGENIZED
18GROUPGAMMA INFHOMMEDIUM
  U-233       1   0.0    1.15983E-15     317   END
  U-234       1   0.0    6.60430E-06     317   END
  U-235       1   0.0    5.82311E-04     317   END
  U-236       1   0.0    2.66836E-06     317   END
  U-238       1   0.0    3.27635E-05     317   END
  SI          1   0.0    4.15914E-04     317   END
  MG       1   0.0    1.3374267E-04     317   END
  AL       1   0.0    2.7905164E-02     317   END
  SI       1   0.0    1.4059918E-04     317   END
  TI       1   0.0    1.0183909E-05     317   END
  CR       1   0.0    1.2503453E-05     317   END
  MN       1   0.0    1.2917070E-05     317   END
  FE       1   0.0    8.0506777E-05     317   END
  ZN       1   0.0    2.2142766E-05     317   END
  ZN       1   0.0    1.9222156E-05     317   END
  D      1   0.0    2.94852E-02    317   END
  O      1   0.0    1.47426E-02    317   END
  H      1   0.0    1.00000E-15    317   END
  O      1   0.0    1.00000E-15    317   END
  B4C    1      1.00000E-15       317   END
H         2 0   6.686-3    317  END
O         2 0   3.343-2    317  END
H         3 0   1.402-2    317  END
O         3 0   4.654-2    317  END
NA        3 0   9.822-4    317  END
AL        3 0   1.776-3    317  END
SI        3 0   1.869-2    317  END
CA        3 0   1.545-3    317  END
FE        3 0   3.522-4    317  END
FE        4 0   5.9788-2   317  END
CR        4 0   1.8347-2   317  END
NI        4 0   8.1250-3   317  END
MG        5   0.0    6.68713E-04     317   END
AL        5   0.0    5.82195E-02     317   END
SI        5   0.0    3.47224E-04     317   END
TI        5   0.0    5.09195E-05     317   END
CR        5   0.0    6.25173E-05     317   END
MN        5   0.0    4.43768E-05     317   END
FE        5   0.0    2.03729E-04     317   END
ZN        5   0.0    7.60718E-05     317   END
ZN        5   0.0    6.21488E-05     317   END
U-233     6   0      1.00-15         317   END
U-234     6   0      5.92-6          317   END
U-235     6   0      5.22-4          317   END
U-236     6   0      2.39-6          317   END
U-238     6   0      2.94-5          317   END
SI        6   0      3.73-4          317   END
```

```
MG        6    0        1.34-4            317    END
AL        6    0        2.81-2            317    END
SI        6    0        1.42-4            317    END
TI        6    0        1.02-5            317    END
CR        6    0        1.25-5            317    END
MN        6    0        1.30-5            317    END
FE        6    0        8.11-5            317    END
ZN        6    0        2.22-5            317    END
ZN        6    0        1.93-5            317    END
D         6    0        2.95-2            317    END
O         6    0        1.47-2            317    END
   END COMP
 SHIELDING PROBLEM
 NOD=2 RAN=2451A226C357 NOP=2 NIT=1000 MSM=1 END
9.0+6     7.25+6     5.75+6     4.55+6     3.55+6     2.75+6
2.25+6    1.83+6     1.495+6    1.165+6    0.9+6      7.0+5
5.0+5     3.5+5      2.5+5      1.5+5      0.75+5     3.0+4
146250    123250     100625     85313      71000      59125
49500     44835      38123      31455      25650      20300
14750     10150      7250       4838       10125      127000
ENERGY FLUX DENSITY
TYPE 04 CONCRETE DOSE FACTORS
 SHIELDING PROBLEM
 0 0 0 0
  RPP    -150.000    650.000   -146.755  570.00   -192.4     700.
  RPP    -150.000    650.000   -116.275  570.00   -152.4     700.
  RPP    -150.000    650.000   -115.640  570.00   -151.765   700.
  RPP   -1000.       1000.     -1000.    1000.    -1000.     1000.
  RPP   -2000.       2000.     -2000.    2000.    -2000.     2000.
  RCC       0.0         0.0       0.0       0.0       0.0     52.7
           24.2
  RCC       0.0         0.0       0.0       0.0       0.0     52.7
            9.5
  RCC       0.0      106.68       0.0       0.0       0.0     52.7
           24.2
  RCC       0.0      106.68       0.0       0.0       0.0     52.7
            9.5
  RCC       0.0      213.4        0.0       0.0       0.0     52.7
           24.2
  RCC       0.0      213.4        0.0       0.0       0.0     52.7
            9.5
  RCC     100.6         0.0       0.0       0.0       0.0     52.7
           24.2
  RCC     100.6         0.0       0.0       0.0       0.0     52.7
            9.5
  RCC     100.6      106.68       0.0       0.0       0.0     52.7
           24.2
  RCC     100.6      106.68       0.0       0.0       0.0     52.7
            9.5
  RCC     100.6      213.4        0.0       0.0       0.0     52.7
           24.2
  RCC     100.6      213.4        0.0       0.0       0.0     52.7
            9.5
  RCC     201.2         0.0       0.0       0.0       0.0     52.7
           24.2
  RCC     201.2         0.0       0.0       0.0       0.0     52.7
            9.5
  RCC     201.2      106.68       0.0       0.0       0.0     52.7
           24.2
  RCC     201.2      106.68       0.0       0.0       0.0     52.7
```

```
          9.5
RCC     201.2          213.4          0.0        0.0        0.0       52.7
          24.2
RCC     201.2          213.4          0.0        0.0        0.0       52.7
          9.5
RCC     301.8            0.0          0.0        0.0        0.0       52.7
          24.2
RCC     301.8            0.0          0.0        0.0        0.0       52.7
          9.5
RCC     301.8          106.68         0.0        0.0        0.0       52.7
          24.2
RCC     301.8          106.68         0.0        0.0        0.0       52.7
          9.5
RCC     301.8          213.4          0.0        0.0        0.0       52.7
          24.2
RCC     301.8          213.4          0.0        0.0        0.0       52.7
          9.5
RCC     402.4            0.0          0.0        0.0        0.0       52.7
          24.2
RCC     402.4            0.0          0.0        0.0        0.0       52.7
          9.5
RCC     402.4          106.68         0.0        0.0        0.0       52.7
          24.2
RCC     402.4          106.68         0.0        0.0        0.0       52.7
          9.5
RCC     402.4          213.4          0.0        0.0        0.0       52.7
          24.2
RCC     402.4          213.4          0.0        0.0        0.0       52.7
          9.5
RCC     503.0            0.0          0.0        0.0        0.0       52.7
          24.2
RCC     503.0            0.0          0.0        0.0        0.0       52.7
          9.5
RCC     503.0          106.68         0.0        0.0        0.0       52.7
          24.2
RCC     503.0          106.68         0.0        0.0        0.0       52.7
          9.5
RCC     503.0          213.4          0.0        0.0        0.0       52.7
          24.2
RCC     503.0          213.4          0.0        0.0        0.0       52.7
          9.5
RCC     0.0              0.0          0.0        0.0        0.0       52.7
          10.2
RCC     0.0              0.0          0.0        0.0        0.0       52.7
          16.8
RCC     0.0              0.0          0.0        0.0        0.0       52.7
          17.5
RCC     0.0              0.0          0.0        0.0        0.0       52.7
          23.5
RCC     0.0              0.0          0.0        0.0        0.0       52.70
          24.2
  END
H2O             3     -6     -8    -10    -12    -14    -16    -18
               -20    -22    -24    -26    -28    -30    -32    -36
               -38    -40
LIN      OR     2     -3
CON      OR     1     -2
VID             4     -1
VIX             5     -4
HIF      OR    40    -41OR    8    -9OR   10    -11OR   12    -13OR   14
```

```
                -15OR   16     -17OR   18     -19OR   20     -21OR   22     -23
          OR    24      -25OR   26     -27OR   28     -29OR   30     -31OR   32
                -33OR   34     -35OR   36     -37OR   38     -39
  COR     OR    7OR    9OR    11OR    13OR    15OR    17OR    19OR    21OR    23
          OR    25OR  27OR    29OR    31OR    33OR    35OR    37OR    39OR    41
  INW             42     -7
  CTW             44     -43
  OTW             46     -45
  INF             43     -42
  OTF             45     -44
    END
    2     2     2     2     2     2     2     1
    1     2     1     1
12*0
    2     4     3    1000     0    1    2    5
    5     5     1     1
 0
150.0 2*0.0 -25.0 25.0 -25.0 25.0  0.0  52.7
36*1
0.0       5.501+2    9.828+3    1.761+12    1.528+14    1.204+16
2.471+16 2.371+16   6.313+17   1.375+17    3.838+17    1.975+18
1.231+18 5.002+17   5.002+17   7.327+17    6.543+17    6.543+17   1.0
  0.0      -92.075       26.35
  0.0          0.0      -152.45
END
```

```
//BM62 JOB ,JUGHEAD,GROUP=J62785,USER=P89709,MSGLEVEL=(1,1),
// TIME=70,NOTIFY=P89709,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.JUGHEAD
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.SYSIN DD *
=SAS3
BENCHMARK AGAINST CRAMER'S CALC. OF THE HFIR:  HOMO FUEL REGIONS
18GROUPGAMMA INFHOMMEDIUM
H       11 0   2.961-2     END
B       11 0   8.779-6     END
C       11 0   2.260-6     END
O       11 0   1.554-2     END
AL      11 0   2.750-2     END
CR      11 0   1.023-3     END
FE      11 0   3.334-3     END
NI      11 0   4.531-4     END
CD      11 0   5.422-4     END
U-238   11 0   2.776-4     END
H        1 0   6.686-3     END
O        1 0   3.343-2     END
H        9 0   1.402-2     END
O        9 0   4.654-2     END
NA       9 0   9.822-4     END
AL       9 0   1.776-3     END
SI       9 0   1.869-2     END
CA       9 0   1.545-3     END
FE       9 0   3.522-4     END
H        2 0   3.3431-2    END
O        2 0   1.8080-2    END
B        2 0   1.6500-5    END
C        2 0   4.1820-6    END
AL       2 0   2.6715-2    END
U-235    2 0   5.1327-4    END
H        4 0   3.3431-2    END
O        4 0   1.6716-2    END
AL       4 0   3.0126-2    END
FE       5 0   5.9788-2    END
CR       5 0   1.8347-2    END
NI       5 0   8.1250-3    END
H        6 0   2.7200-2    END
O        6 0   1.3600-2    END
AL       6 0   1.7973-2    END
CD       6 0   2.8831-3    END
FE       6 0   1.3907-2    END
CR       6 0   4.2675-3    END
NI       6 0   1.8899-3    END
H        7 0   2.7875-2    END
O        7 0   1.3937-2    END
AL       7 0   3.5120-2    END
H        8 0   1.5913-2    END
O        8 0   7.9566-3    END
AL       8 0   2.5513-2    END
CD       8 0   2.5447-3    END
FE       8 0   1.6950-2    END
CR       8 0   5.2014-3    END
NI       8 0   2.3034-3    END
```

```
AL      10 0   6.0230-2    END
CL       3 0   8.5077-3    END
H        3 0   4.2539-2    END
C        3 0   3.4031-2    END
   END COMP
 SHIELDING PROBLEM
 NOD=1 RAN=B199CB4AD7E7 NOP=2 NIT=600 MSM=2 END
9.0+6     7.25+6     5.75+6     4.55+6     3.55+6     2.75+6
2.25+6    1.83+6     1.495+6    1.165+6    0.9+6      7.0+5
5.0+5     3.5+5      2.5+5      1.5+5      0.75+5     3.0+4
146250    123250     100625     85313      71000      59125
49500     44835      38123      31455      25650      20300
14750     10150      7250       4838       10125      127000
ENERGY FLUX DENSITY
CONCRETE DOSE FACTORS
 SHIELDING PROBLEM
 0 0 0 0
  RPP    -150.000    400.000   -80.000   300.00   -100.      300.
  RPP    -150.000    400.000   -61.595   300.00   -71.4375   300.
  RPP    -100.000    400.000   -60.960   300.00   -70.8025   300.
  RPP    -90.1700   -57.1500   -61.595  -13.335   -100.      300.
  RPP    -90.8050   -56.5150   -61.595  -12.700   -70.8025   300.
  RPP    -90.8050   -56.5150   -12.700   0.0000   -70.8025   300.
  RPP    -86.3600   -60.9600   -8.8900   300.00   -70.8025   300.
  RPP    -85.0900   -74.2950   -7.62000  300.00   -69.5325   300.
  RPP    -73.0250   -62.2300   -7.62000  300.00   -69.5325   300.
  RPP   -150.000   -100.000   -60.9600  300.00   -70.8025    300.
  RPP   -30.4800    296.545   -15.6946  238.5796 -9.8425    -7.3025
  RPP   -150.000    400.000   -80.0000  -75.000  -100.000    300.0
  RPP   -1000.      1000.     -1000.    1000.    -1000.     1000.
  RPP   -2000.      2000.     -2000.    2000.    -2000.     2000.
  RCC       0.0       0.0       0.0       0.0       0.0     60.96
          22.6327
  RCC       0.0       0.0       0.0       0.0       0.0     60.96
          5.014
  RCC       0.0     75.565      0.0       0.0       0.0     60.96
          22.6327
  RCC       0.0     75.565      0.0       0.0       0.0     60.96
          5.014
  RCC       0.0     151.13      0.0       0.0       0.0     60.96
          22.6327
  RCC       0.0     151.13      0.0       0.0       0.0     60.96
          5.014
  RCC    55.245       0.0       0.0       0.0       0.0     60.96
          22.6327
  RCC    55.245       0.0       0.0       0.0       0.0     60.96
          5.014
  RCC    55.245     75.565      0.0       0.0       0.0     60.96
          22.6327
  RCC    55.245     75.565      0.0       0.0       0.0     60.96
          5.014
  RCC    55.245     151.13      0.0       0.0       0.0     60.96
          22.6327
  RCC    55.245     151.13      0.0       0.0       0.0     60.96
          5.014
  RCC    110.49       0.0       0.0       0.0       0.0     60.96
          22.6327
  RCC    110.49       0.0       0.0       0.0       0.0     60.96
          5.014
  RCC    110.49     75.565      0.0       0.0       0.0     60.96
```

```
          22.6327
RCC     110.49      75.565          0.0       0.0       0.0      60.96
          5.014
RCC     110.49      151.13          0.0       0.0       0.0      60.96
          22.6327
RCC     110.49      151.13          0.0       0.0       0.0      60.96
          5.014
RCC     165.735        0.0          0.0       0.0       0.0      60.96
          22.6327
RCC     165.735        0.0          0.0       0.0       0.0      60.96
          5.014
RCC     165.735     75.565          0.0       0.0       0.0      60.96
          22.6327
RCC     165.735     75.565          0.0       0.0       0.0      60.96
          5.014
RCC     165.735     151.13          0.0       0.0       0.0      60.96
          22.6327
RCC     165.735     151.13          0.0       0.0       0.0      60.96
          5.014
RCC     220.98         0.0          0.0       0.0       0.0      60.96
          22.6327
RCC     220.98         0.0          0.0       0.0       0.0      60.96
          5.014
RCC     220.98      75.565          0.0       0.0       0.0      60.96
          22.6327
RCC     220.98      75.565          0.0       0.0       0.0      60.96
          5.014
RCC     220.98      151.13          0.0       0.0       0.0      60.96
          22.6327
RCC     220.98      151.13          0.0       0.0       0.0      60.96
          5.014
RCC     276.225        0.0          0.0       0.0       0.0      60.96
          22.6327
RCC     276.225        0.0          0.0       0.0       0.0      60.96
          5.014
RCC     276.225     75.565          0.0       0.0       0.0      60.96
          22.6327
RCC     276.225     75.565          0.0       0.0       0.0      60.96
          5.014
RCC     276.225     151.13          0.0       0.0       0.0      60.96
          22.6327
RCC     276.225     151.13          0.0       0.0       0.0      60.96
          5.014
RCC     0.0            0.0          0.0       0.0       0.0      60.96
          7.1412
RCC     0.0            0.0         5.08       0.0       0.0      50.8
          12.5976
RCC     0.0            0.0          0.0       0.0       0.0      60.96
          12.5976
RCC     0.0            0.0          0.0       0.0       0.0      60.96
          15.1226
RCC     0.0            0.0         5.08       0.0       0.0      50.80
          20.9332
RCC     0.0            0.0          0.0       0.0       0.0      60.96
          20.9332
RCC     0.0            0.0          0.0       0.0       0.0      60.96
          22.6327
  END
VID     OR    8OR    9
ALM           7     -8     -9
```

```
   RUX            6      -7
   H2O            3      -6      -7     -10      -5     -11     -15     -17     -19
                -21     -23     -25     -27     -29     -31     -33     -35     -37
                -39     -41     -43     -45     -47     -49
   H20           10
   LIN      OR    2      -3      -5     -10OR     5      -4
   CON      OR    1      -2      -4     -12OR     4
   CON           12
   PLT           11
   VID           13      -1     -12
   VIX           14     -13
   HIF      OR   49     -50OR    17     -18OR    19     -20OR    21     -22OR    23
                -24OR    25     -26OR    27     -28OR    29     -30OR    31     -32
            OR   33     -34OR    35     -36OR    37     -38OR    39     -40OR    41
                -42OR    43     -44OR    45     -46OR    47     -48
   H20      OR   16OR    18OR    20OR    22OR    24OR    26OR    28OR    30OR    32
            OR   34OR    36OR    38OR    40OR    42OR    44OR    46OR    48OR    50
   INW           51     -16
   CTW           54     -53
   OTW           57     -56
   INF           52     -51
   OTF           55     -54
   FBU      OR   53     -52     -51OR    56     -55     -54
     END
     2     2     2     2     1     2     2     1     2     2     2     2     2     1
     1     2     1     1     1
19*0
 1000    10     3     1     1     5     9     9     5  1000     0    11  1000     6
     7     8     2     2     4
 0
150.0 2*0.0 -25.0 25.0 -25.0 25.0  0.0  61.0
36*1
4.24-9 1.72-7 2.328+11 2.328+11 3.361+13
3.821+15 3.559+15 7.235+16 3.984+16 4.533+16
1.91+17 2.679+17 2.944+17 7.167+16 1.529+17
2.656+17 1.947+17 0.0 1.0
  0.0     -61.6     30.48
END
```

```
//CEMMAS20 JOB ,RCJONES,GROUP=J62785,USER=P89719,MSGLEVEL=(1,1),
// TIME=15,NOTIFY=P89719,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.RCJONES
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//*GO.FT98F001 DD UNIT=SYSDA,SPACE=(TRK,(30,10),RLSE),
//* DCB=(RECFM=VBS,LRECL=X,BLKSIZE=9440,BUFL=10232)
//GO.SYSIN DD *
=SAS1          PARM='SIZE=700000'
18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H2O,91.44CM CONCRETE (CYL)
18GROUPGAMMA
MULTIREGION
'------------------------
'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
H2O     1                          END
'
U-233   2       0       1.000-15 END
U-234   2       0       7.100-6  END
U-235   2       0       6.260-4  END
U-236   2       0       2.870-6  END
U-238   2       0       3.520-5  END
SI      2       0       4.470-4  END
MG      2       0       1.340-4  END
AL      2       0       2.790-2  END
SI      2       0       1.410-4  END
TI      2       0       1.020-5  END
CR      2       0       1.250-5  END
MN      2       0       1.290-5  END
FE      2       0       8.050-5  END
ZN      2       0       1.920-5  END
'
H2O     3                          END
'
SS304   4       END
'
H       5       0       1.308-2  END
O       5       0       4.466-2  END
MG      5       0       5.795-4  END
AL      5       0       2.164-3  END
SI      5       0       2.638-3  END
P       5       0       1.166-5  END
S       5       0       6.947-5  END
CA      5       0       3.606-3  END
TI      5       0       1.205-3  END
V       5       0       7.327-5  END
CR      5       0       3.473-5  END
MN      5       0       2.630-5  END
FE      5       0       1.880-2  END
'------------------------
END COMP
CYLINDRICAL  END
'----------------------
'DISTANCE FROM THE ORIGIN TO THE OUTERMOST POINT OF EACH ZONE
1       17.5000
2       24.0000
3       84.0000
4       89.0800
```

```
5       139.0800
 END ZONE
END
LAST
CONCRETE DOSE IN 50CM CONCRETE (CYLINDRICAL)
CYLINDRICAL
'
' THE 8TH NUMBER IS THE TOTAL SOURCE STRENGTH DIVIDED BY THE FUEL VOLUME
' WHERE THE FUEL VOLUME IS 39,182 CM3 (H=46.24 CM)
'ZONE, RADII,   MESH PTS, FUEL IDENTIFIER,OTHER INFO
1       17.5000   18       0
2       24.0000   14      -1              0 0 0.0  1.61220E+13
3       84.0000   60       0
4       89.0800    6       0
5       139.0800  50       0
 END ZONE
'18 GROUP GAMMA SOURCE SPECTRUM (ANS UPPER CORE) FOR DECAY OF 2 CYCLES (DKPOWR)
'-----------------------------------------------------------------------
0.000E+00    5.501E+02    9.828E+03    1.761E+12    1.528E+14    1.204E+16
2.471E+16    2.371E+16    6.313E+17    1.375E+17    3.838E+17    1.975E+18
1.231E+18    5.002E+17    5.002E+17    7.327E+17    6.543E+17    6.543E+17
'0.000E+00    9.072E-05    2.791E+01    2.178E-02    1.029E+13    8.692E+14
'1.644E+15    4.762E+13    4.565E+16    5.514E+14    1.638E+16    3.408E+17
'9.978E+16    8.981E+15    8.981E+15    6.735E+16    2.035E+16    2.035E+16
'-----------------------------------------------------------------------
'NDETEC=? SIGNIFIES USER WILL SPECIFY DETECTOR LOCATIONS
'NDETEC=2
' ID1=0 PRINTS SCALAR GAMMA FLUXES BY INTERVAL
ID1=0
' NFACTR=1 SIGNALS ONE FLUX TO DOSE CONVERSION ID NUMBER TO BE INPUT
NFACTR=1
' DY=, DZ= ARE DIMENSIONS OF SLAB TO USE IN BUCKLING CORRECTION
'DY=254.00
'DZ=254.00
READ XSDOSE
'304.80CM IS THE SHIELD HEIGHT (ASSUMED TO BE 10 FEET)
304.80
'9504 INDICATES ANSI STANDARD GAMMA-RAY-FLUX-TO-DOSE RATE FACTORS(RAD/HR)
9504
END
```

```
//CEMMA JOB ,RCJONES,GROUP=J62785,USER=P89719,MSGLEVEL=(1,1),
// TIME=15,NOTIFY=P89719,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.RCJONES
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//*GO.FT98F001 DD UNIT=SYSDA,SPACE=(TRK,(30,10),RLSE),
//* DCB=(RECFM=VBS,LRECL=X,BLKSIZE=9440,BUFL=10232)
//GO.SYSIN DD *
=SAS1          PARM='SIZE=700000'
18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H20,91.44CM CONCRETE (CYL)
18GROUPGAMMA
MULTIREGION
'------------------------
'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
H2O     1                           END
'
U-233   2       0       1.000-15 END
U-234   2       0       7.100-6  END
U-235   2       0       6.260-4  END
U-236   2       0       2.870-6  END
U-238   2       0       3.520-5  END
SI      2       0       4.470-4  END
MG      2       0       1.340-4  END
AL      2       0       2.790-2  END
SI      2       0       1.410-4  END
TI      2       0       1.020-5  END
CR      2       0       1.250-5  END
MN      2       0       1.290-5  END
FE      2       0       8.050-5  END
ZN      2       0       1.920-5  END
'
H2O     3                           END
'
H       4       0       1.308-2  END
O       4       0       4.466-2  END
MG      4       0       5.795-4  END
AL      4       0       2.164-3  END
SI      4       0       2.638-3  END
P       4       0       1.166-5  END
S       4       0       6.947-5  END
CA      4       0       3.606-3  END
TI      4       0       1.205-3  END
V       4       0       7.327-5  END
CR      4       0       3.473-5  END
MN      4       0       2.630-5  END
FE      4       0       1.880-2  END
'------------------------
END COMP
CYLINDRICAL  END
'------------------------
'DISTANCE FROM THE ORIGIN TO THE OUTERMOST POINT OF EACH ZONE
1       17.5000
2       24.0000
3       74.4400
4       174.4400
 END ZONE
END
```

```
LAST
CONCRETE DOSE IN 91.44CM CONCRETE (CYLINDRICAL)
CYLINDRICAL
'
' THE 8TH NUMBER IS THE TOTAL SOURCE STRENGTH DIVIDED BY THE FUEL VOLUME
' WHERE THE FUEL VOLUME IS 39,182 CM3 (H=46.24 CM)
'ZONE, RADII,   MESH PTS, FUEL IDENTIFIER,OTHER INFO
1       17.5000   18       0
2       24.0000   14      -1              0 0 0.0  1.61220E+13
3       74.4400   50       0
4       174.4400 100       0
 END ZONE
'18 GROUP GAMMA SOURCE SPECTRUM (ANS UPPER CORE) FOR DECAY OF 2 CYCLES (DKPOWR)
'-------------------------------------------------------------------------
0.000E+00    5.501E+02    9.828E+03    1.761E+12    1.528E+14    1.204E+16
2.471E+16    2.371E+16    6.313E+17    1.375E+17    3.838E+17    1.975E+18
1.231E+18    5.002E+17    5.002E+17    7.327E+17    6.543E+17    6.543E+17
'0.000E+00    9.072E-05    2.791E+01    2.178E-02    1.029E+13    8.692E+14
'1.644E+15    4.762E+13    4.565E+16    5.514E+14    1.638E+16    3.408E+17
'9.978E+16    8.981E+15    8.981E+15    6.735E+16    2.035E+16    2.035E+16
'-------------------------------------------------------------------------
'NDETEC=? SIGNIFIES USER WILL SPECIFY DETECTOR LOCATIONS
'NDETEC=2
' ID1=0 PRINTS SCALAR GAMMA FLUXES BY INTERVAL
ID1=0
' NFACTR=1 SIGNALS ONE FLUX TO DOSE CONVERSION ID NUMBER TO BE INPUT
NFACTR=1
' DY=, DZ= ARE DIMENSIONS OF SLAB TO USE IN BUCKLING CORRECTION
'DY=254.00
'DZ=254.00
READ XSDOSE
'304.80CM IS THE SHIELD HEIGHT (ASSUMED TO BE 10 FEET)
304.80
'9504 INDICATES ANSI STANDARD GAMMA-RAY-FLUX-TO-DOSE RATE FACTORS(RAD/HR)
9504
END
```

```
//CEM03 JOB ,RCJONES,GROUP=J62785,USER=P89719,MSGLEVEL=(1,1),
// TIME=15,NOTIFY=P89719,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.RCJONES
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//*GO.FT98F001 DD UNIT=SYSDA,SPACE=(TRK,(30,10),RLSE),
//* DCB=(RECFM=VBS,LRECL=X,BLKSIZE=9440,BUFL=10232)
//GO.SYSIN DD *
=SAS1          PARM='SIZE=700000'
18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H20,91.44CM CONCRETE (CYL)
18GROUPGAMMA
MULTIREGION
'------------------------
'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
H2O     1                          END
'
U-233   2       0       1.000-15 END
U-234   2       0       7.100-6  END
U-235   2       0       6.260-4  END
U-236   2       0       2.870-6  END
U-238   2       0       3.520-5  END
SI      2       0       4.470-4  END
MG      2       0       1.340-4  END
AL      2       0       2.790-2  END
SI      2       0       1.410-4  END
TI      2       0       1.020-5  END
CR      2       0       1.250-5  END
MN      2       0       1.290-5  END
FE      2       0       8.050-5  END
ZN      2       0       1.920-5  END
'
H2O     3                          END
'
H       4       0       1.945-2  END
O       4       0       4.286-2  END
C       4       0       5.914-3  END
MG      4       0       1.412-3  END
AL      4       0       1.897-3  END
SI      4       0       7.329-3  END
P       4       0       1.361-4  END
S       4       0       1.314-4  END
K       4       0       6.158-5  END
CA      4       0       8.742-3  END
FE      4       0       3.234-5  END
NI      4       0       2.666-4  END
'------------------------
END COMP
CYLINDRICAL  END
'------------------------
'DISTANCE FROM THE ORIGIN TO THE OUTERMOST POINT OF EACH ZONE
1       17.5000
2       24.0000
3       74.4400
4       174.4400
 END ZONE
END
LAST
```

```
CONCRETE DOSE IN 91.44CM CONCRETE (CYLINDRICAL)
CYLINDRICAL
'
' THE 8TH NUMBER IS THE TOTAL SOURCE STRENGTH DIVIDED BY THE FUEL VOLUME
' WHERE THE FUEL VOLUME IS 39,182 CM3 (H=46.24 CM)
'ZONE, RADII,   MESH PTS, FUEL IDENTIFIER,OTHER INFO
1       17.5000   18       0
2       24.0000   14      -1              0 0 0.0  1.61220E+13
3       74.4400   50       0
4       174.4400 100       0
 END ZONE
'18 GROUP GAMMA SOURCE SPECTRUM (ANS UPPER CORE) FOR DECAY OF 2 CYCLES (DKPOWR)
'-------------------------------------------------------------------------
0.000E+00    5.501E+02    9.828E+03    1.761E+12    1.528E+14    1.204E+16
2.471E+16    2.371E+16    6.313E+17    1.375E+17    3.838E+17    1.975E+18
1.231E+18    5.002E+17    5.002E+17    7.327E+17    6.543E+17    6.543E+17
'0.000E+00    9.072E-05    2.791E+01    2.178E-02    1.029E+13    8.692E+14
'1.644E+15    4.762E+13    4.565E+16    5.514E+14    1.638E+16    3.408E+17
'9.978E+16    8.981E+15    8.981E+15    6.735E+16    2.035E+16    2.035E+16
'-------------------------------------------------------------------------
'NDETEC=? SIGNIFIES USER WILL SPECIFY DETECTOR LOCATIONS
'NDETEC=2
' ID1=0 PRINTS SCALAR GAMMA FLUXES BY INTERVAL
ID1=0
' NFACTR=1 SIGNALS ONE FLUX TO DOSE CONVERSION ID NUMBER TO BE INPUT
NFACTR=1
' DY=, DZ= ARE DIMENSIONS OF SLAB TO USE IN BUCKLING CORRECTION
'DY=254.00
'DZ=254.00
READ XSDOSE
'304.80CM IS THE SHIELD HEIGHT (ASSUMED TO BE 10 FEET)
304.80
'9504 INDICATES ANSI STANDARD GAMMA-RAY-FLUX-TO-DOSE RATE FACTORS(RAD/HR)
9504
END
```

```
//S00HALF JOB ,RCJONES,GROUP=J62785,USER=P89719,MSGLEVEL=(1,1),
// TIME=15,NOTIFY=P89719,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.RCJONES
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//*GO.FT98F001 DD UNIT=SYSDA,SPACE=(TRK,(30,10),RLSE),
//* DCB=(RECFM=VBS,LRECL=X,BLKSIZE=9440,BUFL=10232)
//GO.SYSIN DD *
=SAS1          PARM='SIZE=700000'
18 GROUP,2 CYCLE DK ANS SOURCE,91.44CM H20,91.44CM CONCRETE (CYL)
18GROUPGAMMA
MULTIREGION
'------------------------
'MAT.,ZONE,VOLUME FRACT,NUMBER DENSITY
H2O     1                          END
'
U-233   2       0       1.000-15 END
U-234   2       0       7.100-6  END
U-235   2       0       6.260-4  END
U-236   2       0       2.870-6  END
U-238   2       0       3.520-5  END
SI      2       0       4.470-4  END
MG      2       0       1.340-4  END
AL      2       0       2.790-2  END
SI      2       0       1.410-4  END
TI      2       0       1.020-5  END
CR      2       0       1.250-5  END
MN      2       0       1.290-5  END
FE      2       0       8.050-5  END
ZN      2       0       1.920-5  END
'
H2O     3                          END
'
'SS304  4       END
'
H       4       0       1.402-2  END
O       4       0       4.654-2  END
NA      4       0       9.822-4  END
AL      4       0       1.776-3  END
SI      4       0       1.689-2  END
CA      4       0       1.545-3  END
FE      4       0       3.522-4  END
'------------------------
END COMP
CYLINDRICAL  END
'------------------------
'DISTANCE FROM THE ORIGIN TO THE OUTERMOST POINT OF EACH ZONE
1       17.5000
2       24.0000
3       74.0000
4       124.0000
 END ZONE
END
LAST
CONCRETE DOSE IN 91.44CM CONCRETE (CYLINDRICAL), 1 SS304 PLATE - 1/2INCH THICK
CYLINDRICAL
'
```

```
' THE 8TH NUMBER IS THE TOTAL SOURCE STRENGTH DIVIDED BY THE FUEL VOLUME
' WHERE THE FUEL VOLUME IS 39,182 CM3 (H=46.24 CM)
'ZONE, RADII,   MESH PTS, FUEL IDENTIFIER,OTHER INFO
1       17.5000   18       0
2       24.0000   14      -1              0 0 0.0  1.61220E+13
3       74.0000   50       0
4       124.0000  50       0
 END ZONE
'18 GROUP GAMMA SOURCE SPECTRUM (ANS UPPER CORE) FOR DECAY OF 2 CYCLES (DKPOWR)
'-------------------------------------------------------------------------
0.000E+00    5.501E+02    9.828E+03    1.761E+12    1.528E+14    1.204E+16
2.471E+16    2.371E+16    6.313E+17    1.375E+17    3.838E+17    1.975E+18
1.231E+18    5.002E+17    5.002E+17    7.327E+17    6.543E+17    6.543E+17
'0.000E+00    9.072E-05    2.791E+01    2.178E-02    1.029E+13    8.692E+14
'1.644E+15    4.762E+13    4.565E+16    5.514E+14    1.638E+16    3.408E+17
'9.978E+16    8.981E+15    8.981E+15    6.735E+16    2.035E+16    2.035E+16
'-------------------------------------------------------------------------
'NDETEC=? SIGNIFIES USER WILL SPECIFY DETECTOR LOCATIONS
'NDETEC=2
' ID1=0 PRINTS SCALAR GAMMA FLUXES BY INTERVAL
ID1=0
' NFACTR=1 SIGNALS ONE FLUX TO DOSE CONVERSION ID NUMBER TO BE INPUT
NFACTR=1
' DY=, DZ= ARE DIMENSIONS OF SLAB TO USE IN BUCKLING CORRECTION
'DY=254.00
'DZ=254.00
READ XSDOSE
'304.80CM IS THE SHIELD HEIGHT (ASSUMED TO BE 10 FEET)
304.80
'9504 INDICATES ANSI STANDARD GAMMA-RAY-FLUX-TO-DOSE RATE FACTORS(RAD/HR)
9504
END
```

```
//CS1XLOWR JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=250,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT03F001 DD UNIT=ONLINE,DSN=J62785.XSXNLO25,
// SPACE=(TRK,(20,10)),DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6200,BUFL=6200)
//GO.SYSIN DD *
=CSAS1X
'''=CSAS1X   PARM=CHECK
ANS-L7 CSAS1X  U3SI2+AL  CSAS1X_MULTIREGION_RX[ANS]  LOWER ELEMENT HOMOGENIZED
27BURNUPLIB  MULTIREGION
'
' _________
' *** JCASE_FUEL =^JCASE_FUEL^ ***
' *** JCASE_FUEL =          1  ***
'
' _________
' *** MODEL_REACTOR = ^MODEL_REACTOR ^
' *** MODEL_REACTOR =                1
' *** MODEL_HF      = ^MODEL_HF      ^
' *** MODEL_HF      =                2
' *** MODEL_CPBT    = ^MODEL_CPBT    ^
' *** MODEL_CPBT    =                2
' *** MODEL_FUEL    = ^MODEL_FUEL    ^
' *** MODEL_FUEL    =                1
' *** MODEL_ELEMENT = ^MODEL_ELEMENT ^
' *** MODEL_ELEMENT =                4
'
'
' _________
' *** WATER CENTRAL
  D      1   0.0    5.95609E-02    322.15   END
  O      1   0.0    2.97805E-02    322.15   END
  H      1   0.0    1.00000E-15    322.15   END
  O      1   0.0    1.00000E-15    322.15   END
'
' _________
' ***           4=LOWER ELEMENT WITHOUT HF
'
' _________
' ***           2=DOUBLE HF
'
  _________
  D      2   0.0    5.95609E-02    322.15   END
  O      2   0.0    2.97805E-02    322.15   END
  H      2   0.0    1.00000E-15    322.15   END
  O      2   0.0    1.00000E-15    322.15   END
'
  _________
  D      3   0.0    5.95609E-02    322.15   END
  O      3   0.0    2.97805E-02    322.15   END
  H      3   0.0    1.00000E-15    322.15   END
  O      3   0.0    1.00000E-15    322.15   END
'
  _________
  D      4   0.0    5.95609E-02    322.15   END
  O      4   0.0    2.97805E-02    322.15   END
  H      4   0.0    1.00000E-15    322.15   END
  O      4   0.0    1.00000E-15    322.15   END
'
  _________
  D      5   0.0    5.95609E-02    322.15   END
  O      5   0.0    2.97805E-02    322.15   END
  H      5   0.0    1.00000E-15    322.15   END
```

```
  O       5    0.0     1.00000E-15     322.15    END
'
  ________
  D       6    0.0     5.95609E-02     322.15    END
  O       6    0.0     2.97805E-02     322.15    END
  H       6    0.0     1.00000E-15     322.15    END
  O       6    0.0     1.00000E-15     322.15    END
'
  ________
  D       7    0.0     5.95609E-02     322.15    END
  O       7    0.0     2.97805E-02     322.15    END
  H       7    0.0     1.00000E-15     322.15    END
  O       7    0.0     1.00000E-15     322.15    END
'
  ________
  D       8    0.0     5.95609E-02     322.15    END
  O       8    0.0     2.97805E-02     322.15    END
  H       8    0.0     1.00000E-15     322.15    END
  O       8    0.0     1.00000E-15     322.15    END
'
  ________
  D       9    0.0     5.95609E-02     322.15    END
  O       9    0.0     2.97805E-02     322.15    END
  H       9    0.0     1.00000E-15     322.15    END
  O       9    0.0     1.00000E-15     322.15    END
'
  ________
  D      10    0.0     5.95609E-02     322.15    END
  O      10    0.0     2.97805E-02     322.15    END
  H      10    0.0     1.00000E-15     322.15    END
  O      10    0.0     1.00000E-15     322.15    END
'
  ________
  MG         11    0.0     6.68713E-04     339.15    END
  AL         11    0.0     5.82195E-02     339.15    END
  SI         11    0.0     3.47224E-04     339.15    END
  TI         11    0.0     5.09195E-05     339.15    END
  CR         11    0.0     6.25173E-05     339.15    END
  MN         11    0.0     4.43768E-05     339.15    END
  FE         11    0.0     2.03729E-04     339.15    END
  CU         11    0.0     7.60718E-05     339.15    END
  CU         11    0.0     6.21488E-05     339.15    END
'
' ________
' ***                4=LOWER ELEMENT WITHOUT HF
'
' ________
' ***                1=SINGLE FUEL
' *** SC         MX    VF      ND                  TEMP
  U-233          12    0.0     1.00000E-15         505.37    END
  U-234          12    0.0     5.92106E-06         505.37    END
  U-235          12    0.0     5.21753E-04         505.37    END
  U-236          12    0.0     2.38988E-06         505.37    END
  U-238          12    0.0     2.93959E-05         505.37    END
  SI             12    0.0     3.72973E-04         505.37    END
'
  ________
  MG         12    0.0     1.3374267E-04       505.37    END
  AL         12    0.0     2.8139977E-02       505.37    END
  SI         12    0.0     1.4162666E-04       505.37    END
  TI         12    0.0     1.0183909E-05       505.37    END
  CR         12    0.0     1.2503453E-05       505.37    END
  MN         12    0.0     1.2975433E-05       505.37    END
  FE         12    0.0     8.1080927E-05       505.37    END
  CU         12    0.0     2.2242812E-05       505.37    END
  CU         12    0.0     1.9320239E-05       505.37    END
'
' ________
' *** WATER FUEL
  D       12    0.0     2.94852E-02     339.15    END
```

```
O       12    0.0     1.47426E-02     339.15    END
H       12    0.0     1.00000E-15     339.15    END
O       12    0.0     1.00000E-15     339.15    END
,
_________
B4C     12      1.00000E-15         339.15    END
,
,
_________
' *** OUTER AL LOWER ELEMENT  AND  INNER AL  UPPER ELEMENT (AL6061)
MG          13    0.0     6.68713E-04      339.15    END
AL          13    0.0     5.82195E-02      339.15    END
SI          13    0.0     3.47224E-04      339.15    END
TI          13    0.0     5.09195E-05      339.15    END
CR          13    0.0     6.25173E-05      339.15    END
MN          13    0.0     4.43768E-05      339.15    END
FE          13    0.0     2.03729E-04      339.15    END
CU          13    0.0     7.60718E-05      339.15    END
CU          13    0.0     6.21488E-05      339.15    END
,
_________
D         14    0.0     5.89704E-02     339.15    END
O         14    0.0     2.94852E-02     339.15    END
H         14    0.0     1.00000E-15     339.15    END
O         14    0.0     1.00000E-15     339.15    END
,
_________
MG          15    0.0     6.68713E-04      339.15    END
AL          15    0.0     5.82195E-02      339.15    END
SI          15    0.0     3.47224E-04      339.15    END
TI          15    0.0     5.09195E-05      339.15    END
CR          15    0.0     6.25173E-05      339.15    END
MN          15    0.0     4.43768E-05      339.15    END
FE          15    0.0     2.03729E-04      339.15    END
CU          15    0.0     7.60718E-05      339.15    END
CU          15    0.0     6.21488E-05      339.15    END
,
_________
' *** WATER BETWEEN OUTER AL UPPER ELEMENT AND CPBT
D         16    0.0     5.89704E-02     339.15    END
O         16    0.0     2.94852E-02     339.15    END
H         16    0.0     1.00000E-15     339.15    END
O         16    0.0     1.00000E-15     339.15    END
,
_________
MG          17    0.0     6.68713E-04      322.15    END
AL          17    0.0     5.82195E-02      322.15    END
SI          17    0.0     3.47224E-04      322.15    END
TI          17    0.0     5.09195E-05      322.15    END
CR          17    0.0     6.25173E-05      322.15    END
MN          17    0.0     4.43768E-05      322.15    END
FE          17    0.0     2.03729E-04      322.15    END
CU          17    0.0     7.60718E-05      322.15    END
CU          17    0.0     6.21488E-05      322.15    END
,
_________
D         18    0.0     5.94656E-02     322.15    END
O         18    0.0     2.97328E-02     322.15    END
H         18    0.0     1.00000E-15     322.15    END
O         18    0.0     1.00000E-15     322.15    END
,
_________
MG        19   0.0     6.68713E-04       322.15    END
AL        19   0.0     5.82195E-02       322.15    END
SI        19   0.0     3.47224E-04       322.15    END
TI        19   0.0     5.09195E-05       322.15    END
CR        19   0.0     6.25173E-05       322.15    END
MN        19   0.0     4.43768E-05       322.15    END
```

```
  FE       19  0.0    2.03729E-04       322.15   END
  CU       19  0.0    7.60718E-05       322.15   END
  CU       19  0.0    6.21488E-05       322.15   END
'
  D        20   0.0    1.00000E-15      322.15   END
  O        20   0.0    1.00000E-15      322.15   END
  H        20   0.0    6.61105E-02      322.15   END
  O        20   0.0    3.30552E-02      322.15   END
END COMP
CYLINDRICAL    END
       1  1.00000E-01
       2  1.74272
       3  2.39272
       4  3.51772
       5  3.91772
       6  5.18228
       7  5.83228
       8  6.13228
       9  6.53228
      10  9.50000
      11 10.20000
      12 16.80000
      13 17.50000
      14 23.50000
      15 24.20000
      16 24.50000
      17 25.30000
      18 175.3000
      19 178.3000
      20 198.3000
END ZONE
MORE DATA
'
' *** INNER   OUTER
'     IIM=20  ICM=25
'
' *** NOTE : CSAS1X IS NORMALLY S8P3       S8=ISN     P3=ISCT
' *** NOTE : RESETTING OF /P1/ /P3/ /P5/ INSIDE #CSAS1X  IS NOT AVAILABLE
'     ISN=8
'
' *** NOTE : BAL = KEY TO PRINT BALANCE TABLES
' ***        BAL=ALL : PRINTS ALL BALANCE TABLES
' ***        BAL=FINE : PRINTS ONLY THE FINE-GROUP BALANCE TABLES (DEFAULT)
' ***        BAL=NONE : CAUSES THE BALANCE TABLE PRINT TO BE SUPPRESSED
'''     BAL=NONE
'
' *** NOTE : AXIAL BUCKLING CORRECTION
' *** 31.2" * 10 BLOCKS = 312.0" = 792.48 CM
'     DY=100.0
'
' *** NOTE : COF = DIFFUSION COEFFICIENT OPTION FOR TRANSVERSE LEAKAGE
' ***              CORRECTION (SEE 3$$ A7(IPN)   IPN=0 (DEFAULT)
'     COF=0
'     COF=2
'
' ***  5  ICM=    MAX.NUMBER OF OUTER ITERATIONS THE DEFAULT VALUE IS 25.
' ***             THIS ALLOWS USING ANOTHER VALUE.
' ***  6  EPS=    OVERALL CONVERGENCE CRITERIA   THE DEFAULT VALUE IS 0.0001.
' ***             THIS ALLOWS USING ANOTHER VALUE.
' ***  7  PTC=    POINT CONVERGENCE CRITERIA     THE DEFAULT VALUE IS 0.0001.
```

```
' ***              THIS ALLOWS USING ANOTHER VALUE.
         ICM=25  EPS=1.0E-4  PTC=1.0E-4
'        ICM=30  EPS=1.0E-6  PTC=1.0E-6
'        ICM=40  EPS=1.0E-7  PTC=1.0E-7
' *** NEXT : FOR TESTING ONLY
'''         ICM=2
'
' ***  3  SZF=    SPATIAL MESH SIZE FACTOR       THE DEFAULT VALUE IS 1.0
' ***             SZF<1.0 GIVES A FINER MESH   SZF>1.0 GIVES A COARSER MESH
'     SZF=1.0
'     SZF=2.0
'''      SZF=-1.0
   END MORE
'''     2     6     2     4     4     6     2     4     4     9
'''     2    18     3    18     4     3     3   100     6    12
END
```

```
//CS1XUPPR JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=250,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT03F001 DD UNIT=ONLINE,DSN=J62785.XSXNUP25,
// SPACE=(TRK,(20,10)),DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6200,BUFL=6200)
//GO.SYSIN DD *
=CSAS1X
ANS-L7  CSAS1X  U3SI2+AL  CSAS1X_MULTIREGION_RX[ANS] UPPER ELEMENT HOMOGENIZED
27BURNUPLIB  MULTIREGION
'
'
' ________
' *** JCASE_FUEL =^JCASE_FUEL^ ***
' *** JCASE_FUEL =          1  ***
'
' ________
' *** MODEL_REACTOR = ^MODEL_REACTOR ^
' *** MODEL_REACTOR =                1
' *** MODEL_HF      = ^MODEL_HF      ^
' *** MODEL_HF      =                2
' *** MODEL_CPBT    = ^MODEL_CPBT    ^
' *** MODEL_CPBT    =                2
' *** MODEL_FUEL    = ^MODEL_FUEL    ^
' *** MODEL_FUEL    =                1
' *** MODEL_ELEMENT = ^MODEL_ELEMENT ^
' *** MODEL_ELEMENT =                2
'
'
' _________
' *** WATER CENTRAL
  D       1   0.0    5.95609E-02    322.15   END
  O       1   0.0    2.97805E-02    322.15   END
  H       1   0.0    1.00000E-15    322.15   END
  O       1   0.0    1.00000E-15    322.15   END
'
' ________
' ***           2=UPPER ELEMENT WITHOUT HF
'
' ________
' ***           2=DOUBLE HF
'
  ________
  D       2   0.0    5.95609E-02    322.15   END
  O       2   0.0    2.97805E-02    322.15   END
  H       2   0.0    1.00000E-15    322.15   END
  O       2   0.0    1.00000E-15    322.15   END
'
  ________
  D       3   0.0    5.95609E-02    322.15   END
  O       3   0.0    2.97805E-02    322.15   END
  H       3   0.0    1.00000E-15    322.15   END
  O       3   0.0    1.00000E-15    322.15   END
'
  ________
  D       4   0.0    5.95609E-02    322.15   END
  O       4   0.0    2.97805E-02    322.15   END
  H       4   0.0    1.00000E-15    322.15   END
  O       4   0.0    1.00000E-15    322.15   END
'
  ________
  D       5   0.0    5.95609E-02    322.15   END
  O       5   0.0    2.97805E-02    322.15   END
  H       5   0.0    1.00000E-15    322.15   END
```

```
  O       5    0.0     1.00000E-15     322.15    END
,
  ________
  D       6    0.0     5.95609E-02     322.15    END
  O       6    0.0     2.97805E-02     322.15    END
  H       6    0.0     1.00000E-15     322.15    END
  O       6    0.0     1.00000E-15     322.15    END
,
  ________
  D       7    0.0     5.95609E-02     322.15    END
  O       7    0.0     2.97805E-02     322.15    END
  H       7    0.0     1.00000E-15     322.15    END
  O       7    0.0     1.00000E-15     322.15    END
,
  ________
  D       8    0.0     5.95609E-02     322.15    END
  O       8    0.0     2.97805E-02     322.15    END
  H       8    0.0     1.00000E-15     322.15    END
  O       8    0.0     1.00000E-15     322.15    END
,
  ________
  D       9    0.0     5.95609E-02     322.15    END
  O       9    0.0     2.97805E-02     322.15    END
  H       9    0.0     1.00000E-15     322.15    END
  O       9    0.0     1.00000E-15     322.15    END
,
  ________
  D       10   0.0     5.95609E-02     322.15    END
  O       10   0.0     2.97805E-02     322.15    END
  H       10   0.0     1.00000E-15     322.15    END
  O       10   0.0     1.00000E-15     322.15    END
,
  ________
  MG      11   0.0     6.68713E-04     339.15    END
  AL      11   0.0     5.82195E-02     339.15    END
  SI      11   0.0     3.47224E-04     339.15    END
  TI      11   0.0     5.09195E-05     339.15    END
  CR      11   0.0     6.25173E-05     339.15    END
  MN      11   0.0     4.43768E-05     339.15    END
  FE      11   0.0     2.03729E-04     339.15    END
  CU      11   0.0     7.60718E-05     339.15    END
  CU      11   0.0     6.21488E-05     339.15    END
,
  ________
  D       12   0.0     5.89704E-02     339.15    END
  O       12   0.0     2.94852E-02     339.15    END
  H       12   0.0     1.00000E-15     339.15    END
  O       12   0.0     1.00000E-15     339.15    END
,
  ________
' *** OUTER AL LOWER ELEMENT  AND  INNER AL  UPPER ELEMENT (AL6061)
  MG      13   0.0     6.68713E-04     339.15    END
  AL      13   0.0     5.82195E-02     339.15    END
  SI      13   0.0     3.47224E-04     339.15    END
  TI      13   0.0     5.09195E-05     339.15    END
  CR      13   0.0     6.25173E-05     339.15    END
  MN      13   0.0     4.43768E-05     339.15    END
  FE      13   0.0     2.03729E-04     339.15    END
  CU      13   0.0     7.60718E-05     339.15    END
  CU      13   0.0     6.21488E-05     339.15    END
,
  ________
' ***              1=SINGLE FUEL
,
  ________
' *** SC      MX   VF      ND              TEMP
  U-233       14   0.0     1.00000E-15     505.37    END
  U-234       14   0.0     7.09956E-06     505.37    END
  U-235       14   0.0     6.25601E-04     505.37    END
  U-236       14   0.0     2.86555E-06     505.37    END
```

```
U-238        14   0.0    3.52468E-05      505.37   END
SI           14   0.0    4.47209E-04      505.37   END
'
'
MG        14    0.0     1.3374267E-04      505.37   END
AL        14    0.0     2.7905164E-02      505.37   END
SI        14    0.0     1.4059918E-04      505.37   END
TI        14    0.0     1.0183909E-05      505.37   END
CR        14    0.0     1.2503453E-05      505.37   END
MN        14    0.0     1.2917070E-05      505.37   END
FE        14    0.0     8.0506777E-05      505.37   END
CU        14    0.0     2.2142766E-05      505.37   END
CU        14    0.0     1.9222156E-05      505.37   END
'
'
' *** WATER FUEL
D       14    0.0     2.94852E-02     339.15   END
O       14    0.0     1.47426E-02     339.15   END
H       14    0.0     1.00000E-15     339.15   END
O       14    0.0     1.00000E-15     339.15   END
'
'
B4C     14      1.00000E-15        339.15   END
'
'
'
MG        15    0.0     6.68713E-04       339.15   END
AL        15    0.0     5.82195E-02       339.15   END
SI        15    0.0     3.47224E-04       339.15   END
TI        15    0.0     5.09195E-05       339.15   END
CR        15    0.0     6.25173E-05       339.15   END
MN        15    0.0     4.43768E-05       339.15   END
FE        15    0.0     2.03729E-04       339.15   END
CU        15    0.0     7.60718E-05       339.15   END
CU        15    0.0     6.21488E-05       339.15   END
'
'
' *** WATER BETWEEN OUTER AL UPPER ELEMENT AND CPBT
D       16    0.0     5.89704E-02     339.15   END
O       16    0.0     2.94852E-02     339.15   END
H       16    0.0     1.00000E-15     339.15   END
O       16    0.0     1.00000E-15     339.15   END
'
'
MG        17    0.0     6.68713E-04       322.15   END
AL        17    0.0     5.82195E-02       322.15   END
SI        17    0.0     3.47224E-04       322.15   END
TI        17    0.0     5.09195E-05       322.15   END
CR        17    0.0     6.25173E-05       322.15   END
MN        17    0.0     4.43768E-05       322.15   END
FE        17    0.0     2.03729E-04       322.15   END
CU        17    0.0     7.60718E-05       322.15   END
CU        17    0.0     6.21488E-05       322.15   END
'
'
D       18    0.0     5.94656E-02     322.15   END
O       18    0.0     2.97328E-02     322.15   END
H       18    0.0     1.00000E-15     322.15   END
O       18    0.0     1.00000E-15     322.15   END
'
'
MG        19   0.0     6.68713E-04       322.15   END
AL        19   0.0     5.82195E-02       322.15   END
SI        19   0.0     3.47224E-04       322.15   END
TI        19   0.0     5.09195E-05       322.15   END
CR        19   0.0     6.25173E-05       322.15   END
MN        19   0.0     4.43768E-05       322.15   END
FE        19   0.0     2.03729E-04       322.15   END
```

```
  CU       19  0.0    7.60718E-05       322.15   END
  CU       19  0.0    6.21488E-05       322.15   END
'
  _________
  D        20   0.0     1.00000E-15     322.15   END
  O        20   0.0     1.00000E-15     322.15   END
  H        20   0.0     6.61105E-02     322.15   END
  O        20   0.0     3.30552E-02     322.15   END
'
END COMP
CYLINDRICAL    END
'
  _________
        1  1.0000E-01
        2  1.74272
        3  2.39272
        4  3.51772
        5  3.91772
        6  5.18228
        7  5.83228
        8  6.13228
        9  6.53228
       10  9.50000
       11 10.20000
       12 16.80000
       13 17.50000
       14 24.10000
       15 24.80000
       16 25.10000
       17 25.90000
       18 175.9000
       19 178.9000
       20 198.9000
END ZONE
MORE DATA
'
' _________
' *** INNER   OUTER
'     IIM=20  ICM=25
'
' _________
' *** NOTE : CSAS1X IS NORMALLY S8P3      S8=ISN     P3=ISCT
' *** NOTE : RESETTING OF /P1/ /P3/ /P5/ INSIDE #CSAS1X  IS NOT AVAILABLE
'     ISN=8
'
' _________
' *** NOTE : BAL = KEY TO PRINT BALANCE TABLES
' ***        BAL=ALL : PRINTS ALL BALANCE TABLES
' ***        BAL=FINE : PRINTS ONLY THE FINE-GROUP BALANCE TABLES (DEFAULT)
' ***        BAL=NONE : CAUSES THE BALANCE TABLE PRINT TO BE SUPPRESSED
'''     BAL=NONE
'
' _________
' *** NOTE : AXIAL BUCKLING CORRECTION
'     DY=100.0
'
' _________
' *** NOTE : COF = DIFFUSION COEFFICIENT OPTION FOR TRANSVERSE LEAKAGE
' ***              CORRECTION (SEE 3$$ A7(IPN)   IPN=0 (DEFAULT)
'     COF=0
'     COF=2
'
' _________
' ***  5  ICM=    MAX.NUMBER OF OUTER ITERATIONS THE DEFAULT VALUE IS 25.
' ***             THIS ALLOWS USING ANOTHER VALUE.
' ***  6  EPS=    OVERALL CONVERGENCE CRITERIA   THE DEFAULT VALUE IS 0.0001.
' ***             THIS ALLOWS USING ANOTHER VALUE.
' ***  7  PTC=    POINT CONVERGENCE CRITERIA     THE DEFAULT VALUE IS 0.0001.
```

```
' ***              THIS ALLOWS USING ANOTHER VALUE.
          ICM=25  EPS=1.0E-4  PTC=1.0E-4
'         ICM=30  EPS=1.0E-6  PTC=1.0E-6
'         ICM=40  EPS=1.0E-7  PTC=1.0E-7
' *** NEXT : FOR TESTING ONLY
'''          ICM=2
'
' ********
' ***  3  SZF=    SPATIAL MESH SIZE FACTOR       THE DEFAULT VALUE IS 1.0
' ***             SZF<1.0 GIVES A FINER MESH   SZF>1.0 GIVES A COARSER MESH
'     SZF=1.0
'     SZF=2.0
'''      SZF=-1.0
     END MORE
'''     2     6     2     4     4     6     2     4     4     9
'''     2    18     3    18     4     3     3   100     6    12
END
```

```
//CUPLLOWR JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=5,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT34F001 DD DSN=J62785.BSCLWRPB,DISP=SHR
//GO.FT33F001 DD DSN=J62785.XSXNLO25,DISP=SHR
//GO.FT32F001 DD UNIT=ONLINE,DSN=J62785.XSXNLO25.COUPLE,
// SPACE=(3604,(70,8),RLSE),DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6128,BUFL=6200)
//GO.SYSIN DD *
=COUPLE
       ANS CORE L7 LOWER ELEMENT (HOMOGENIZED)
         165 MW IN LOWER CORE (APPROXIMATION)
                    COUPLE MODULE

0$$ A3 33 A4 34 A6 32 E
1$$ A12 922350 A16 1 7 15 5 E  2** 330.65 E 1T
EDIT

0$$ A4 32 E  1$$ A2 1 A5 1 A13 -1 E 1T
DONE
END
```

```
//CUPLUPPR JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=5,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT34F001 DD DSN=J62785.BSCLWRPB,DISP=SHR
//GO.FT33F001 DD DSN=J62785.XSXNUP25,DISP=SHR
//GO.FT32F001 DD UNIT=ONLINE,DSN=J62785.XSXNUP25.COUPLE,
// SPACE=(3604,(70,8),RLSE),DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6128,BUFL=6200)
//GO.SYSIN DD *
=COUPLE
       ANS CORE L7 UPPER ELEMENT (HOMOGENIZED)
         165 MW IN UPPER CORE (APPROXIMATION)
                    COUPLE MODULE

0$$ A3 33 A4 34 A6 32 E
1$$ A12 922350 A16 1 7 15 5 E  2** 330.65 E 1T
EDIT

0$$ A4 32 E  1$$ A2 1 A5 1 A13 -1 E 1T
DONE
END
```

```
//MKLBTEST JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=7,MSGCLASS=A,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//*
//*      COUPLE - MAKE BASIC PWR LIBRARY - CASE
//*
//GO.FT34F001 DD UNIT=ONLINE,DSN=J62785.BSCLWRPB,
// SPACE=(3604,(70,8),RLSE),DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=6136,BUFL=6136)
//GO.SYSIN DD *
=COUPLE
BASIC LWR LIBRARY (VERY BASIC - NOT "BIG CASE")
CREATED BY PATRICK S. BRANTLEY ON 3/29/93

0$$  A2 28 A6 34  E
1$$  1 1 A11 1010  E
2**  A2 0.632 0.333 2  1T
3T
35$$  0  5T

0$$  A4 34 E
1$$  A5 1 A13 -1  E  1T
DONE
END
//
```

```
//ORGLO165 JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=5,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT32F001 DD DSN=J62785.XSXNLO25.COUPLE,DISP=SHR
//GO.SYSIN DD *
=ORIGENS
0$$ A4 32 A8 26 E 1$$ 1 1T
ANS CORE L7 LOWER ELEMENT (HOMOGENIZED) - 165 MW
3$$ 32 A3 1 A33 -86 E 2T
35$$ 0 4T
56$$ 17 17 A4 1 A5 0 A6 1 A13 19 4 3 A17 3 E 57** E 5T
ANS CORE L7 LOWER ELEMENT (HOMOGENIZED) - 165 MW
LOWER FUEL ELEMENT - 17 DAY IRRADIATION - 165 MW
58** F165.0 60** 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
73$$ 922330    922340    922350    922360    922380
     140280    120240    130270    140280    220480
     240520    250550    260560    290640    300650
      10020     80160     10010     80160
74**  4.71E-11  0.279    24.588     0.113     1.385
     17.576     6.303  1326.096     6.674     0.480
      0.589     0.611     3.821     1.048     0.910
   1389.493   694.747     4.71E-11  4.71E-11
75$$ 5R2 14R1  6T
56$$ 0 25 A10 17 E 5T
60** 0 1 2 3 4 21 42 63 84 105 126 147 168 189 240 300
     365 548 730 913 1095 1278 1460 1643 1825
65$$ F0 81$$ 2 A3 26 A4 1 E 82$$ F2 6T
0.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1.0 DAYS DECAY - ANS LOWER CORE (165 MW)
2.0 DAYS DECAY - ANS LOWER CORE (165 MW)
3.0 DAYS DECAY - ANS LOWER CORE (165 MW)
4.0 DAYS DECAY - ANS LOWER CORE (165 MW)
21.0 DAYS DECAY - ANS LOWER CORE (165 MW)
42.0 DAYS DECAY - ANS LOWER CORE (165 MW)
63.0 DAYS DECAY - ANS LOWER CORE (165 MW)
84.0 DAYS DECAY - ANS LOWER CORE (165 MW)
105.0 DAYS DECAY - ANS LOWER CORE (165 MW)
126.0 DAYS DECAY - ANS LOWER CORE (165 MW)
147.0 DAYS DECAY - ANS LOWER CORE (165 MW)
168.0 DAYS DECAY - ANS LOWER CORE (165 MW)
189.0 DAYS DECAY - ANS LOWER CORE (165 MW)
240.0 DAYS DECAY - ANS LOWER CORE (165 MW)
300.0 DAYS DECAY - ANS LOWER CORE (165 MW)
365.0 DAYS DECAY - ANS LOWER CORE (165 MW)
548.0 DAYS DECAY - ANS LOWER CORE (165 MW)
730.0 DAYS DECAY - ANS LOWER CORE (165 MW)
913.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1095.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1278.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1460.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1643.0 DAYS DECAY - ANS LOWER CORE (165 MW)
1825.0 DAYS DECAY - ANS LOWER CORE (165 MW)

56$$ F0  T
END
```

```
//ORGUP165 JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=5,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT32F001 DD DSN=J62785.XSXNUP25.COUPLE,DISP=SHR
//GO.SYSIN DD *
=ORIGENS
0$$ A4 32 A8 26 E 1$$ 1 1T
ANS CORE L7 UPPER ELEMENT (HOMOGENIZED) - 165 MW
3$$ 32 A3 1 A33 -86 E 2T
35$$ 0 4T
56$$ 17 17 A4 1 A5 0 A6 1 A13 19 4 3 A17 3 E 57** E 5T
ANS CORE L7 UPPER ELEMENT (HOMOGENIZED) - 165 MW
UPPER FUEL ELEMENT - 17 DAY IRRADIATION - 165 MW
58** F165.0 60** 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
73$$ 922330    922340    922350    922360    922380
     140280    120240    130270    140280    220480
     240520    250550    260560    290640    300650
      10020     80160     10010     80160
74**  6.51E-11  0.462    40.724     0.187     2.290
     29.080     8.717  1815.030     9.173     0.664
      0.813     0.839     5.237     1.438     1.249
   1919.118   956.306  6.51E-11  6.51E-11
75$$ 5R2 14R1  6T
56$$ 0 25 A10 17 E 5T
60** 0 1 2 3 4 21 42 63 84 105 126 147 168 189 240 300
     365 548 730 913 1095 1278 1460 1643 1825
65$$ F0 81$$ 2 A3 26 A4 1 E 82$$ F2 6T
0.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1.0 DAYS DECAY - ANS UPPER CORE (165 MW)
2.0 DAYS DECAY - ANS UPPER CORE (165 MW)
3.0 DAYS DECAY - ANS UPPER CORE (165 MW)
4.0 DAYS DECAY - ANS UPPER CORE (165 MW)
21.0 DAYS DECAY - ANS UPPER CORE (165 MW)
42.0 DAYS DECAY - ANS UPPER CORE (165 MW)
63.0 DAYS DECAY - ANS UPPER CORE (165 MW)
84.0 DAYS DECAY - ANS UPPER CORE (165 MW)
105.0 DAYS DECAY - ANS UPPER CORE (165 MW)
126.0 DAYS DECAY - ANS UPPER CORE (165 MW)
147.0 DAYS DECAY - ANS UPPER CORE (165 MW)
168.0 DAYS DECAY - ANS UPPER CORE (165 MW)
189.0 DAYS DECAY - ANS UPPER CORE (165 MW)
240.0 DAYS DECAY - ANS UPPER CORE (165 MW)
300.0 DAYS DECAY - ANS UPPER CORE (165 MW)
365.0 DAYS DECAY - ANS UPPER CORE (165 MW)
548.0 DAYS DECAY - ANS UPPER CORE (165 MW)
730.0 DAYS DECAY - ANS UPPER CORE (165 MW)
913.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1095.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1278.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1460.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1643.0 DAYS DECAY - ANS UPPER CORE (165 MW)
1825.0 DAYS DECAY - ANS UPPER CORE (165 MW)

56$$ F0  T
END
```

```
//ORGNFULL JOB ,BRANTLEY,GROUP=J62785,USER=P89689,MSGLEVEL=(1,1),
// TIME=5,NOTIFY=P89689,MSGCLASS=D,PASSWORD=?
/*JOBPARM LINES=99
//*
/*ROUTE PRINT UTKVX1.BRANTLEY
//*
//* THIS ORIGEN-S CASE CALCULATES THE DECAY FOR THE FULL
//* ANS CORE L7 USING THE WORKING LIBRARY GENERATED BY
//* A CSAS1X RUN FOR THE UPPER FUEL ELEMENT AND A
//* SUBSEQUENT COUPLE CASE.  THE CORE CONTAINS 15.45 KG
//* OF URANIUM.
//*
//PROCLIB DD DSN=J51041.PROCLIB.CNTL,DISP=SHR
//STEP1 EXEC SCALE41
//GO.FT32F001 DD DSN=J62785.XSXNUP25.COUPLE,DISP=SHR
//GO.SYSIN DD *
=ORIGENS
0$$ A4 32 A8 26 E 1$$ 1 1T
ANS CORE L7 (FULL CORE) (HOMOGENIZED) - 330 MW
3$$ 32 A3 1 A33 -86 E 2T
35$$ 0 4T
56$$ 17 17 A4 1 A5 0 A6 1 A13 19 4 3 A17 3 E 57** E 5T
ANS CORE L7 (FULL CORE) (HOMOGENIZED) - 330 MW
ANS CORE L7 (FULL CORE) (15.45 KG URANIUM)
58** F330.0 60** 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
73$$ 922330    922340    922350    922360    922380
     140280    120240    130270    140280    220480
     240520    250550    260560    290640    300650
      10020     80160     10010     80160
74**  1.12E-10  0.741    65.312     0.299     3.675
     46.656    15.020  3141.126    15.847     1.143
      1.402     1.451     9.058     2.486     2.160
   3308.611  1651.053     1.12E-10  1.12E-10
75$$ 5R2 14R1  6T
56$$ 0 25 A10 17 E 57** E 5T
60** 0 1 2 3 4 21 42 63 84 105 126 147 168 189 240 300
     365 548 730 913 1095 1278 1460 1643 1825
65$$ F0 81$$ 2 A3 26 A4 1 E 82$$ 25R2 6T
0.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
1.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
2.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
3.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
4.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
21.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
42.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
63.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
84.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
105.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
126.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
147.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
168.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
189.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
240.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
300.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
365.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
548.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
730.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
913.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
1095.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
1278.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
```

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1460.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
1643.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)
1825.0 DAYS DECAY - ANS CORE L7 (FULL CORE) (330 MW)

56$$ F0  T
END
```

Appendix D: Concrete Information

Table D.1 Physical Properties of Common Concretes

Type	Average Density (g/cc)	Thermal conductivity (BTU/hrftF)	* Estimated Cost ($/cb yd)
Ordinary	2.30-2.50	0.5	51
Serpentine	2.09	0.5	91
Barytes	2.28-3.50	0.926	425
Magnetites	3.27-3.62	1.54	595
Limonite & Steel	4.08-4.65	1.60	1487

* Based on 1970 prices (4% inflation rate)

Table D.2 Concrete Regulations

Physical Temperature Limitations:

Ordinary	88°C
Serpentine	425°C
Heavy	177°C

NRC Temperature Limitations for All Concretes: 65°C

Maximum Recommended Internal Heat Generation Rate: 0.001 W/cc

Maximum Recommended Incident Energy Flux: 4E+10 MeV/cm^{2}s

Maximum Recommended Temperature Gradient: 1°C/cm

Appendix E: Problem Definition

January 28, 1992

H. L. Dodds

UT Nuclear Engineering Student Project

At this time design requirements have been imposed that require us to maintain a 1524 mm (5 ft.) distance between the spent fuel and the concrete to avoid damaging the concrete due to the gamma heating from the fuel. There will be occasions when this type clearance is going to be very difficult to maintain. We would like to come up with a design that meets the intent of the required spacing without requiring the 5 foot space. There are four locations where design alternatives may need to be considered. These four locations along with comments and ideas on potential solutions are identified below:

1. The light water spent fuel pool

   a. An array of spent fuel elements are stored in this light water pool.

   b. On the order of 2 years accumulation (one element for every 21 days over two years) of fuel elements with various decay heat levels are expected to be stored in this pool.

   c. Presently a 5 foot space requirement from concrete is applied in all directions

   d. Minimize the shuffling of fuel over time

   e. Might identify a special storage rack in middle of pool that would be used to store "x" number of the freshest (from operation) fuel elements. When a new burned element is brought into the pool, the oldest element in the rack would then be moved into the regular storage positions. Under these conditions the distance to concrete would be based on the potential peak gamma heating from the element removed from special storage rack. Check would have to be made to assure that hottest element in special storage rack was not limiting.

   f. Could propose a liner around the concrete so that hottest potential fuel element could be placed much closer to the concrete than 5 feet.

g. Could propose a special cooling system for the surface of the concrete that would allow hottest element to be placed near concrete without overheating concrete. (This solution however has the problem of added expense associated with a new cooling system and the fact that system would have to have a very high reliability).

2) Transfer lock

a. We presently have a transfer lock where the fuel element is transferred from heavy water to light water.

b. Requirement to be 5 feet from concrete at all times makes this transfer lock much larger than desired.

c. Could provide liner in lock to avoid over heating the concrete.

d. Could provide cooling for transfer lock concrete (reliability may not be as important as for light-water pool due to limited time in lock),but would have to consider equipment failure that locks a fuel element in place for a significant period of time.

e. Might determine that for limited time (short times that fuel element would be in lock) higher heating of concrete is allowed. If so, might not have to do anything and still be able to be smaller distances from concrete than 5 feet.

3) Storage location in heavy water

a. Present plans are to store two hottest elements (most recently burned) in heavy water.

b. Requirement for 5 foot space (or equivalent) from concrete adds design complexity.

c. Options similar to those proposed for the light water pool would probably apply.

4) Movement of elements in fuel transfer tunnel

a. Presently in the movement of fuel elements from the refueling stack to the heavy water storage positions the elements would frequently be closer than 5 feet from the concrete.

b. Movement would normally be constant and therefore heating in any one spot would be over a short period of time, but would have to consider equipment failure that locks a fuel element in place for significant period of

time.

A number of questions should probably be addressed before design alternatives are considered. Some of these are listed below:

Are there limited periods of time that a close exposure can be tolerated?
Are there types of concrete that are more tolerate of gamma heating?
Can shielding be added in local areas to reduce the exposure?
What are the extreme consequences if this requirement is not met during a accident?
Is it possible to add cooling in the concrete wall to alleviate this problem?
Is the problem entirely due to the thermal stresses in the concrete?
Is there a problem with material damage due neutron/gamma exposure?
What is the standoff distance with respect to time out of the core?

Many of these questions we can help with or put you in contact with people who can answer or provide insights.

Boyd Maxon of the ANS project staff has agreed to serve as the principle contact with the project for this work. Please contact him for additional information. Please note that this is a real design issue for us and we will follow your progress with great interest.

Douglas L. Selby

Douglas L. Selby, Manager ANS R&D Program, FEDC (4-6161)

Distribution
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Appendix F: Handbook Shielding Analysis

F.1 Theory

For a point source and a point detector, the uncollided component of the detector response is caused by particles traveling in a straight line between the source and the detector. In many situations, it is reasonable to assume that the inscattered particles which influence the detector travel in paths near this line. This assumption is supported by the fact that this path is the shortest distance between the source and the detector and that the angular scattering cross-sections for neutrons and photons are peaked strongly forward. Under these conditions, a simplified handbook shielding analysis may be performed by assuming that all the radiation affecting the detector travels along a ray between the source and the detector.

Since an extended source can be treated as the superposition of a collection of point sources that have independent effects on the detector, the point source formula is the basis for the analytical relationships describing line, surface, and volume sources. The geometry selected for describing the ANS spent fuel storage pool is a uniformly distributed slab source with a slab shield. The total detector response, R(P), describing this arrangement is

$$R(P) = \frac{2\pi \hat{R} S_V}{k_s}\left[E_2(kt) - E_2(k_s L)\right] \qquad (1)$$

where, P = detector position

S_V = slab source strength

E_2 = normalized exponential integral functions

k = shielding slab attenuation coefficient

t = shielding slab thickness

k_S = source slab attenuation coefficient

L = source slab thickness, and

$$\hat{R} = \frac{1.602 \times 10^{-10}}{4\pi}\left(E\frac{\mu_{en}(E)}{\rho}\right) \qquad (2)$$

where, E = the particle energy, and

$\frac{\mu_{en}}{\rho}$ = the linear energy absorption coefficient divided by density.

After the total detector response is determined at location P, a build-up factor, B, may be used to account for scattered component of the detector response. The modified detector response function is thus

$$R(B) = B \times R(P) \qquad (3)$$

Certain regularities exist which permit the use of homogeneous-media buildup factors for shields composed of laminations of two or more different types of materials. A commonly used rule for laminations of two different materials, of thicknesses x_1 and x_2, numbered in the direction from the source to the detector is as follows: If $Z_1 < Z_2$, the overall buildup is approximately equal to the buildup factor B_2 for the higher Z medium with the use of $\mu_1 x_1 + \mu_2 x_2$ as its argument; if $Z_1 > Z_2$, the overall buildup factor to use is the product $B_1(\mu_1 x_1)$ times $B_2(\mu_2 x_2)$.

Using these relationships, a "handbook" analysis was performed to determine the maximum gamma ray dose received by the concrete in the spent fuel storage pool walls. The

results of these calculations were then compared to a similar shielding analysis performed using the SAS1 one dimensional radiation transport code and the TEMPROFV heat transfer code. The following section contains the results of these analyses.

F.2 Results

The gamma ray radiation source used in the "handbook" analysis was an ANS spent core with a source volume of 6.75E+4 cm^3 and a one day decay source spectrum. An eighteen energy group structure was used to represent the source. Fifty centimeters of water and two inches of steel shielded the concrete wall. Table 1 contains the results of the absorbed surface dose rate calculations (Equation 1) for each energy group. The corresponding buildup factors are also presented. Finally, the modified dose rates (Equation 3) are presented.

Using "handbook" methods, the total dose rate received by the concrete wall was calculated to be 6.55 Gy/s. When a similar analysis was performed using the SAS1 one dimensional radiation transport code and the TEMPROFV heat transfer code, the dose rate was calculated to be 1.73 Gy/s. Although the "handbook" calculations yielded a much higher dose rate than the transport code, the two values were of the same order of magnitude. Most of the discrepancy in these values is due to the inaccuracies associated with the buildup factors used in the "handbook" analysis. Assuming the transport codes provide relatively accurate results, the "handbook" analysis clearly produces an overly conservative absorbed dose rate estimation.

The maximum recommended absorbed dose rate in concrete is 0.45 Gy/s. Both the "handbook" analysis and the transport analysis yielded dose rates that exceeded this maximum value. Undoubtedly, the source should be placed further than 50 cm away from the wall.

Table F.1 Absorbed Surface Dose Rate and Buildup Factors

Energy Group	Midpoint Energy (MeV)	Detector Response (Gy/s)	Buildup Factor	Modified Detector Response (Gy/s)
1	9.000	0.000E+00	1.54	0.000E+00
2	7.250	9.395E-15	1.61	1.513E-14
3	5.750	1.387E-13	1.64	2.274E-13
4	4.500	1.997E-05	1.70	3.395E-05
5	3.500	1.338E-03	1.79	2.394E-03
6	2.750	7.462E-02	1.93	1.440E-01
7	2.250	1.185E-01	2.00	2.370E-01
8	1.830	7.972E-02	2.10	1.674E-01
9	1.495	1.274E+00	2.24	2.854E+00
10	1.165	1.659E-01	2.36	3.914E-01
11	0.900	2.495E-01	2.47	6.163E-01
12	0.700	6.410E-01	2.57	1.647E+00
13	0.500	1.583E-01	2.66	4.210E-01
14	0.350	1.949E-02	2.73	5.320E-02
15	0.250	4.656E-03	3.02	1.406E-03
16	0.150	3.328E-04	4.43	1.474E-03
17	0.075	2.807E-13	22.92	6.434E-12
18	0.030	6.283E-134	1.00	6.283E-134

F.3 Handbook Calculations Summary

A "handbook" shielding analysis was performed to determine the absorbed dose rate in the concrete walls of the ANS spent fuel storage pool. The gamma radiation source used in this analysis was an ANS spent core with a source volume of 6.75 cm^3 and a one day decay source strength. Fifty centimeters of water and two inches of steel were placed between the source and the concrete wall. Using "handbook" methods and associated parameters, the absorbed dose rate was calculated to be 6.55 Gy/s. When a similar analysis was performed using the SAS1 one dimensional radiation transport code and the TEMPROV heat transfer code, the dose rate was calculated to be 1.73 Gy/s. Most of the discrepancy in these results is due to the inaccuracies associated with the buildup factors used in "handbook" calculations; consequently, the "handbook" analysis produced an overly conservative dose rate estimation. The maximum recommended absorbed dose rate in concrete is 0.45 Gy/s. Both the "handbook" analysis and the transport calculations yielded dose rates exceeding the recommended limit. Undoubtedly, the source should be placed more than fifty centimeters away from the pool wall.

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